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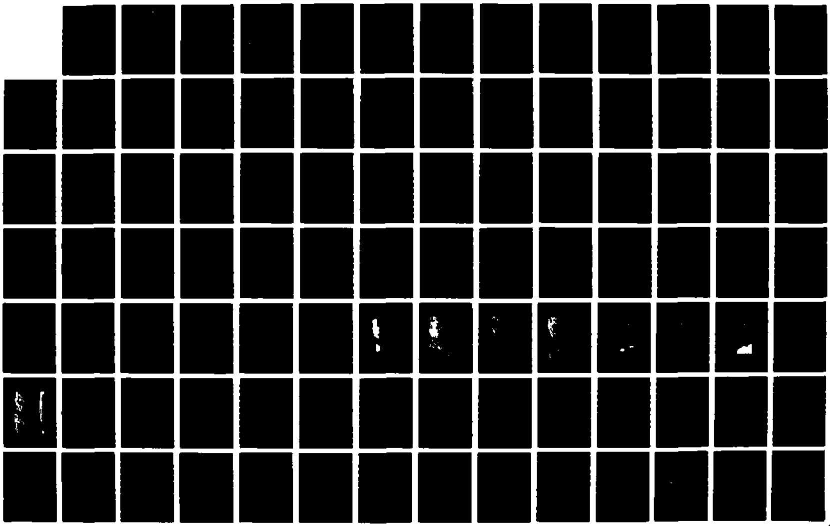

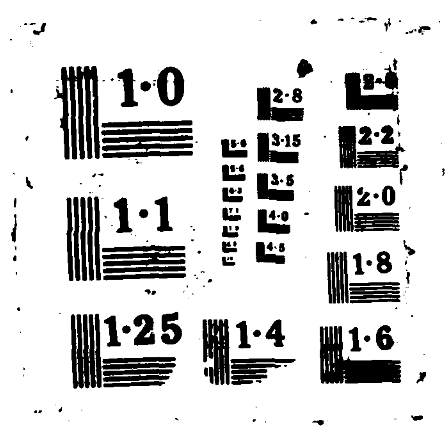
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DASIAC-TN-86-29-V3

TECHNICAL PAPERS PRESENTED AT THE DEFENSE NUCLEAR AGENCY GLOBAL EFFECTS REVIEW

Volume III

Kaman Tempo
Alexandria Office
Huntington Building
2560 Huntington Avenue
Alexandria, VA 22303-1410

15 May 1986

Technical Report

CONTRACT No. DNA 001-82-C-0274

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Prepared for
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REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS:

2a SECURITY CLASSIFICATION AUTHORITY: N/A since Unclassified

2b DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A since Unclassified

3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S):

5 MONITORING ORGANIZATION REPORT NUMBER(S): DASIAC-TN-86-29-V3

6a NAME OF PERFORMING ORGANIZATION: Kaman Tempo

6b OFFICE SYMBOL *(If applicable)*:

7a NAME OF MONITORING ORGANIZATION: Director, Defense Nuclear Agency

6c ADDRESS *(City, State, and ZIP Code)*:
Alexandria Office, Huntington Building
2560 Huntington Avenue
Alexandria, VA 22303-1410

7b ADDRESS *(City, State, and ZIP Code)*: Washington, DC 20305-1000

8a NAME OF FUNDING / SPONSORING ORGANIZATION:

8b OFFICE SYMBOL *(If applicable)*:

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: DNA 001-82-C-0274

8c ADDRESS *(City, State, and ZIP Code)*:

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO
62715H	P99QMXD	C	DH008684

11 TITLE *(Include Security Classification)*:
TECHNICAL PAPERS PRESENTED AT THE DEFENSE NUCLEAR AGENCY GLOBAL EFFECTS REVIEW
Volume III

12 PERSONAL AUTHOR(S): Various

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Technical	FROM 860225 TO 860512	860515	306

16 SUPPLEMENTARY NOTATION:
This work was Sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B331086466 P99QMXDC00003 H2590D

17 COSATI CODES

FIELD	GROUP	SUB-GROUP
04	01	
15	06	

18 SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*:
Nuclear War,
Global Climate Effects.

19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This document contains technical papers presented at the Defense Nuclear Agency Review of Global Effects held at NASA Ames Research Center 25-27 February 1986.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

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22c OFFICE SYMBOL: DNA/CSTI

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PREFACE

The Defense Nuclear Agency has collected and printed the attached papers from the February 25-27 1986 Global Effects review as a service to the community. The Defense Nuclear Agency takes this opportunity to express its gratitude to the numerous participants in the Global Effects review.

The technical papers enclosed include all those which were received by DNA prior to the closing date of 28 April 1986. Where papers are missing their place is occupied by the abstract received prior to the meeting.

The inclusion of a paper in this proceeding does not necessarily imply endorsement of the results of the research reported or conclusions which might be drawn from that research. It is the opinion of the Defense Nuclear Agency that, while good progress is being made in improving our understanding of Global Effects, the results to date are tentative and preliminary and should not be used for planning beyond the planning of future research.

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TABLE OF CONTENTS (Continued)

SECTION 1

GLOBAL MODELING & APPLICATIONS

MODEL VALIDATION STUDIES FOR GLOBAL TRANSPORT: CANDIDATE ANALOGUES

Bob Malone and Gary Glatzmaier

Earth and Space Sciences Division
Los Alamos National Laboratory

PREVIOUS VALIDATION STUDIES

- AEROSOL RESIDENCE TIMES
  - lower and upper troposphere (quantitative)

    [where smoke would be injected]
  - lower stratosphere (qualitative)
- VERTICAL TRANSPORT OF AEROSOLS (qualitative)
  - rapid vertical mixing within troposphere
  - slow penetration from troposphere into stratosphere
  - slow vertical mixing within stratosphere

QUESTIONS ARISING FROM NUCLEAR WINTER SIMULATIONS

- Vertical transport of aerosols due to atmospheric heating by aerosol absorption of solar radiation
  no suitable analogue

- Poleward migration of aerosols injected in midlatitudes
  Arctic haze, heavy methane tracer, volcanic and atmospheric weapons test debris

- Residence time of aerosols in stably stratified layers
  volcanic and weapons test debris (stratosphere)
  Arctic haze (polar inversion layer)

- Rate of dispersion; inhomogeneity; "patchiness"
  heavy methane tracer (troposphere)
  volcanic and weapons test debris (stratosphere)

ISSUES	ARCTIC HAZE	HEAVY METHANE	RADIO-NUCLIDES	VOLCANIC DEBRIS
Region	Troposphere		Stratosphere	
	Lower	Low/Mid	Lower	Lower
Transformations	Yes	None	Neglible	Yes
Removal	Prec/DD	Neglible	Mixing	Mixing
Source Char.	Poor	Excellent	Good	Fair
Ensemble	Continuous	Few	Many	Many
Background	---	None	Variable	Variable
Spatial Extent	Polar	Hemisphere	Global	Global
Observability	Visual + Sampling	Sampling only	Sampling only	Remote + Sampling

- ANALYSIS OF OBSERVATIONAL DATA

  Gene Mroz, Allen Mason, Bill Sedlacek

  Isotope and Nuclear Chemistry Division
  DOE High Altitude Sampling Program

- SEMI-EMPIRICAL DISPERSION MODELS

  Sumner Barr, Frank Gifford

  Earth and Space Science Division

- TURBULENCE MODELING, TRACER TRANSPORT

  Ted Yamada

  Earth and Space Science Division

EULERIAN TRANSPORT MODEL

- Calculates tracer concentration at discrete grid points
- Has same resolution as underlying GCM
- Limitation: number of grid points affordable in GCM

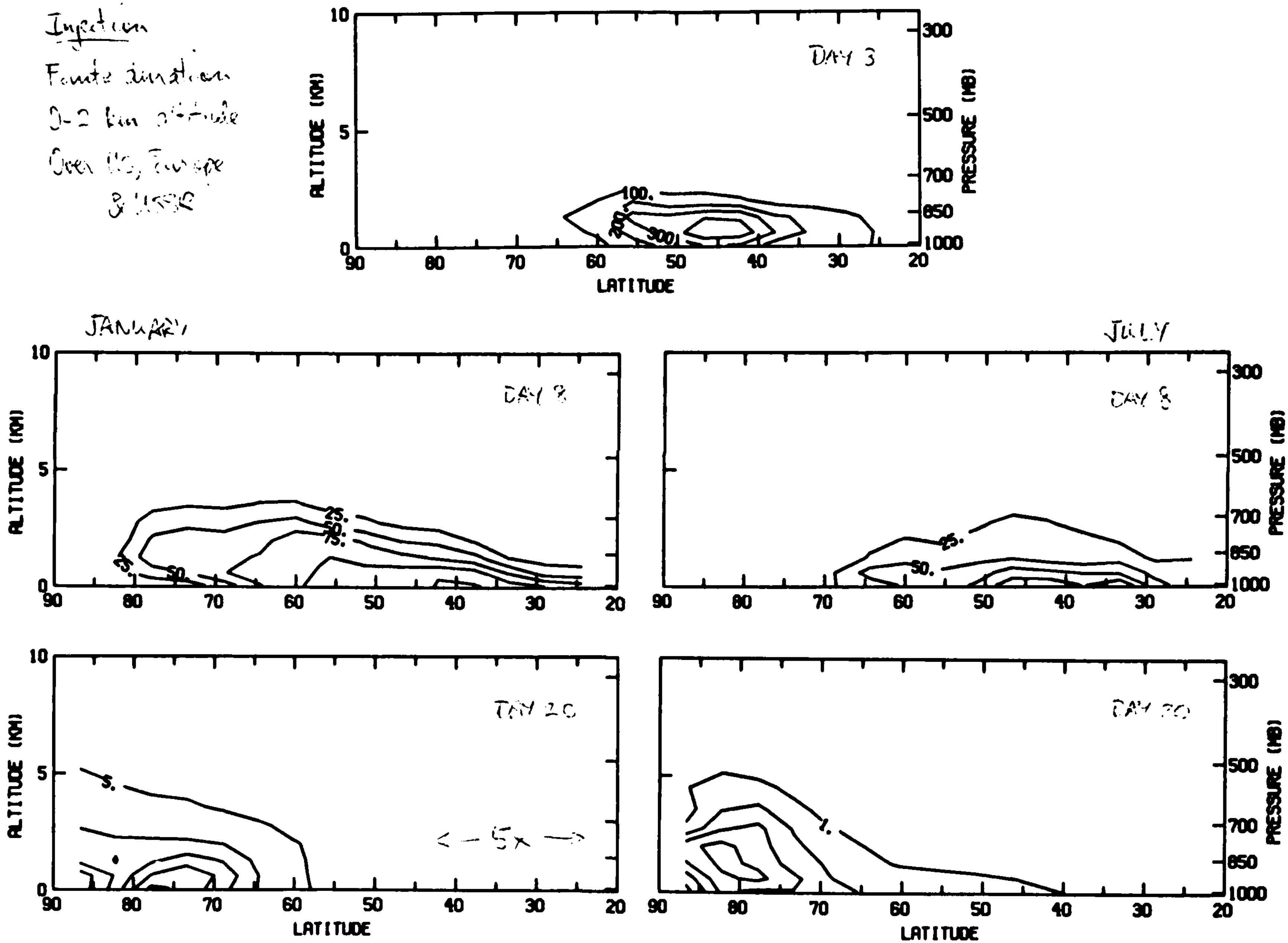
LAGRANGIAN TRACER MODEL

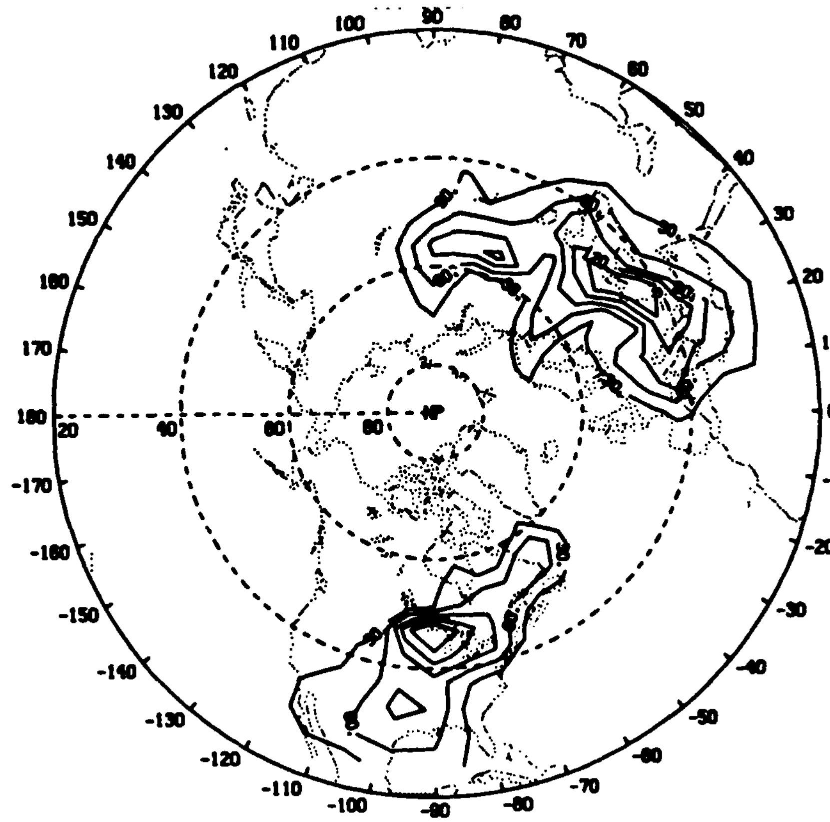
- Tracer is represented by a large number of discrete particles
- Particle coordinates not restricted to GCM grid points
- Limitation: number of particles needed to adequately represent local concentrations on grid

ARCTIC HAZE

- Composed of industrial pollutants (heavy metals, sulfates, organics, gases)
- Major source region: Eurasia, especially USSR
- Pollutants from eastern U.S. are washed out in storm track over North Atlantic
- Pollutants transported directly to Arctic via lower troposphere
- Haze found from surface up to at least 6 km
- Maximum concentration in winter to early spring
- Reasons for winter maximum:
  - pollutants accumulate in stable Eurasian air
  - little precipitation in Arctic in winter
  - vigorous circulation enhances transport

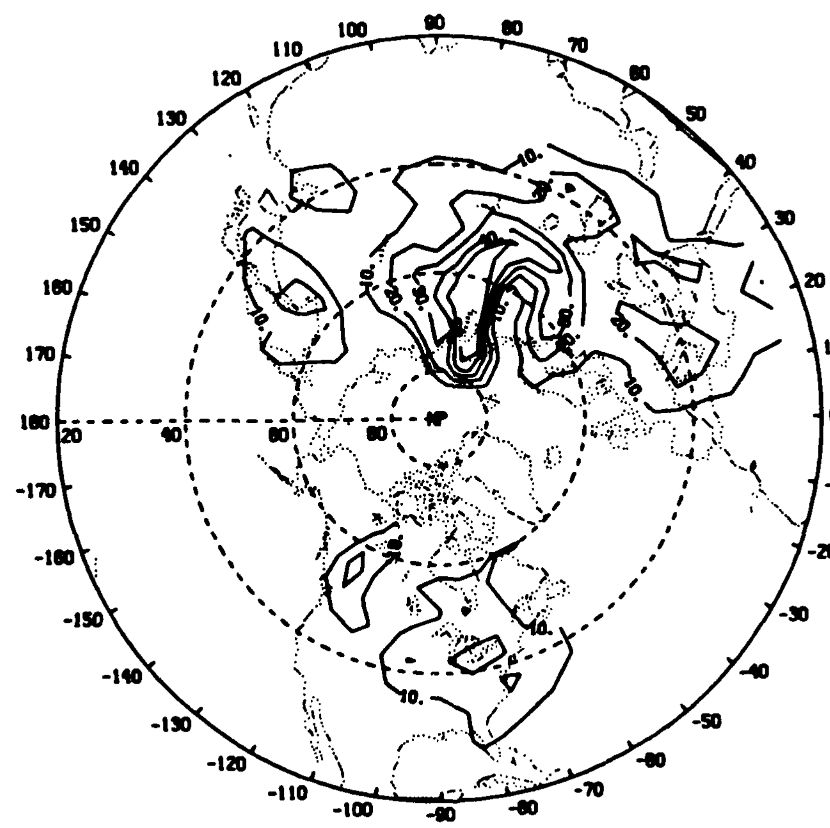
Injection
Finite duration
0-2 km altitude
Over US, Europe
& USSR



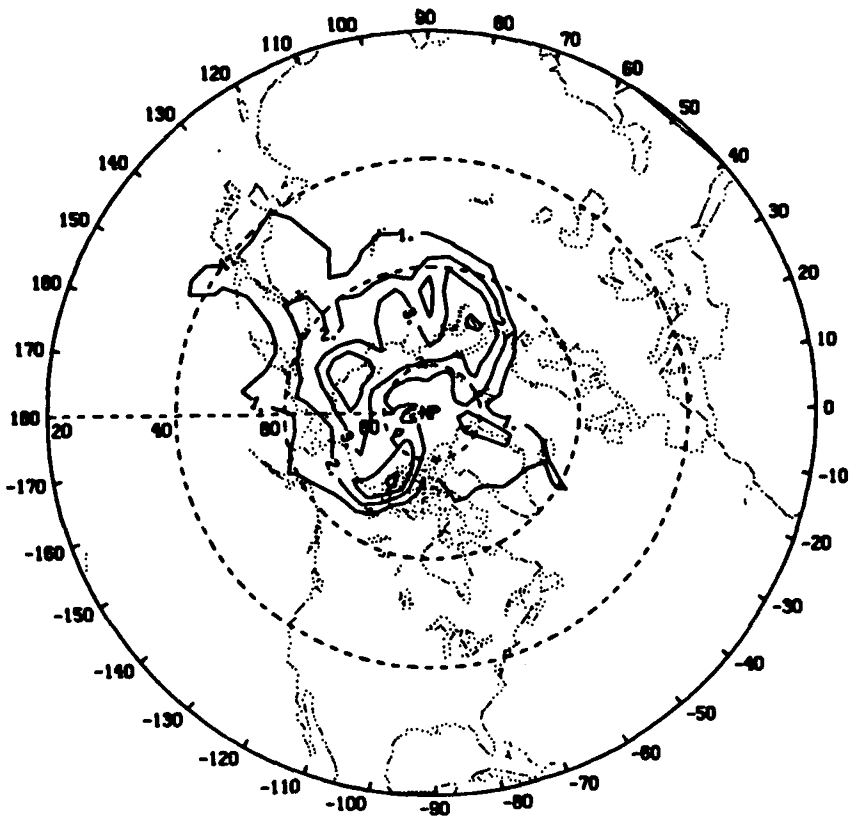


JANUARY

DAY 5



DAY 8



DAY 20

Model correctly portrays (qualitatively)

- **accumulation of pollutants over Eurasia**
- **poleward migration**
- **scavenging of pollutants from North America**
- **seasonal contrast in haze concentration**

AEROSOL RESIDENCE TIMES

TABLE 8-5 (Pruppacher & Klett)
Residence time of atmospheric aerosol particles at various levels in the atmosphere.

Level in the Atmosphere	τ_{AP} Based on evidence prior to 1970	Based on evidence after 1970
Below about 1.5 km	-	0.5 to 2 days
Lower Troposphere	6 days to 2 weeks	2 days to 1 week
Middle and upper Troposphere	2 weeks to 1 month	1 to 2 weeks
Tropopause level	-	3 weeks to 1 month
Lower Stratosphere	6 months to 2 years	1 to 2 months
Upper Stratosphere	2 years to 5 years	1 to 2 years
Lower Mesosphere	5 to 10 years	4 to 20 years

FROM EULERIAN TRANSPORT MODEL

LOWER TROPOSPHERE	< 1 WEEK
UPPER TROPOSPHERE	~ 1.5 WEEKS
LOWER STRATOSPHERE	~ 3 MONTHS

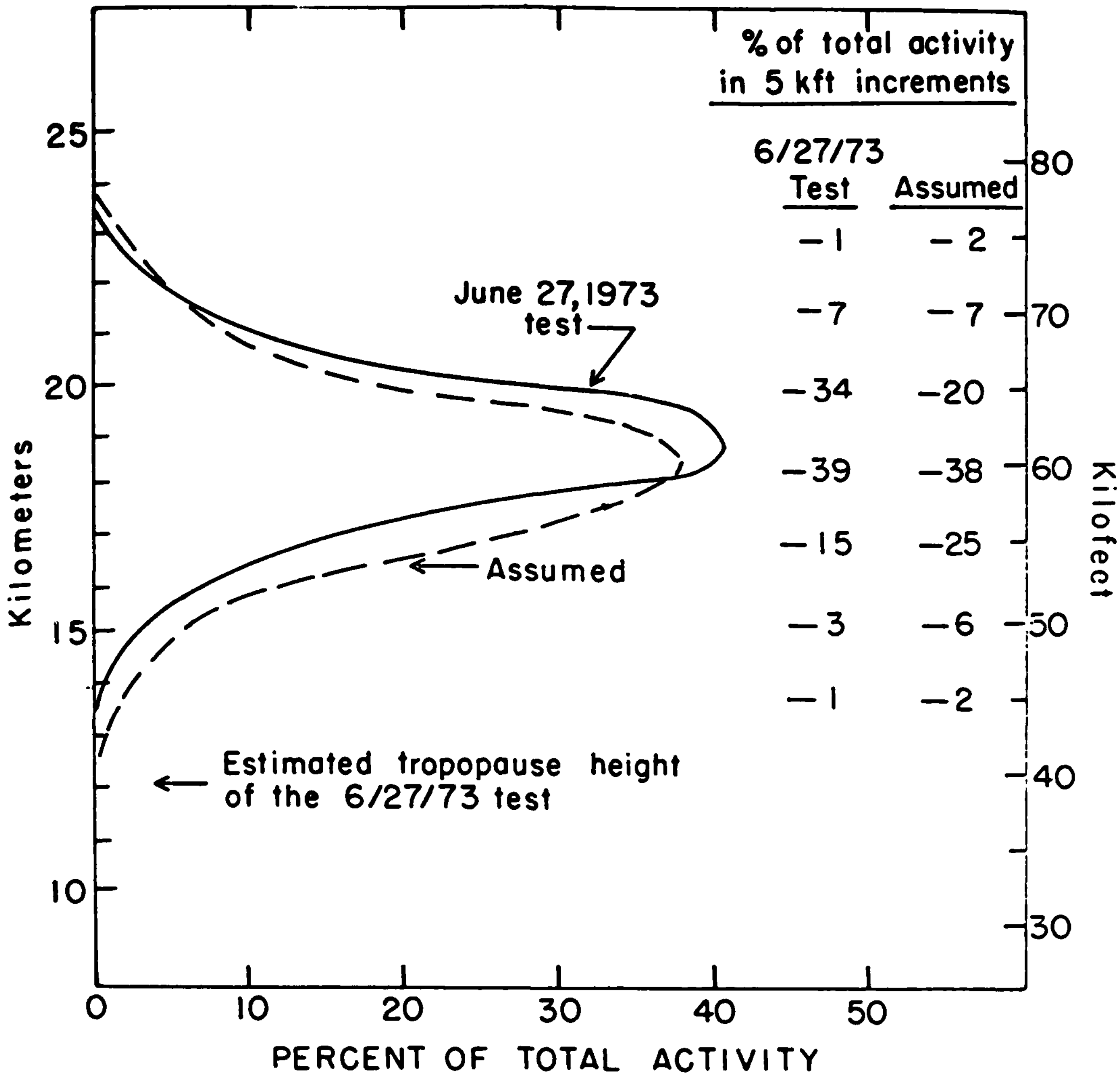


Fig. 8. Comparison of the assumed initial vertical activity distribution for a 3 MT total yield nuclear test in temperate latitudes (based on the 4 earlier high yield Chinese tests) with the estimated initial vertical activity distribution of the June 27, 1973 Chinese test of 2 to 3 MT total yield.

Telegadas (1976)

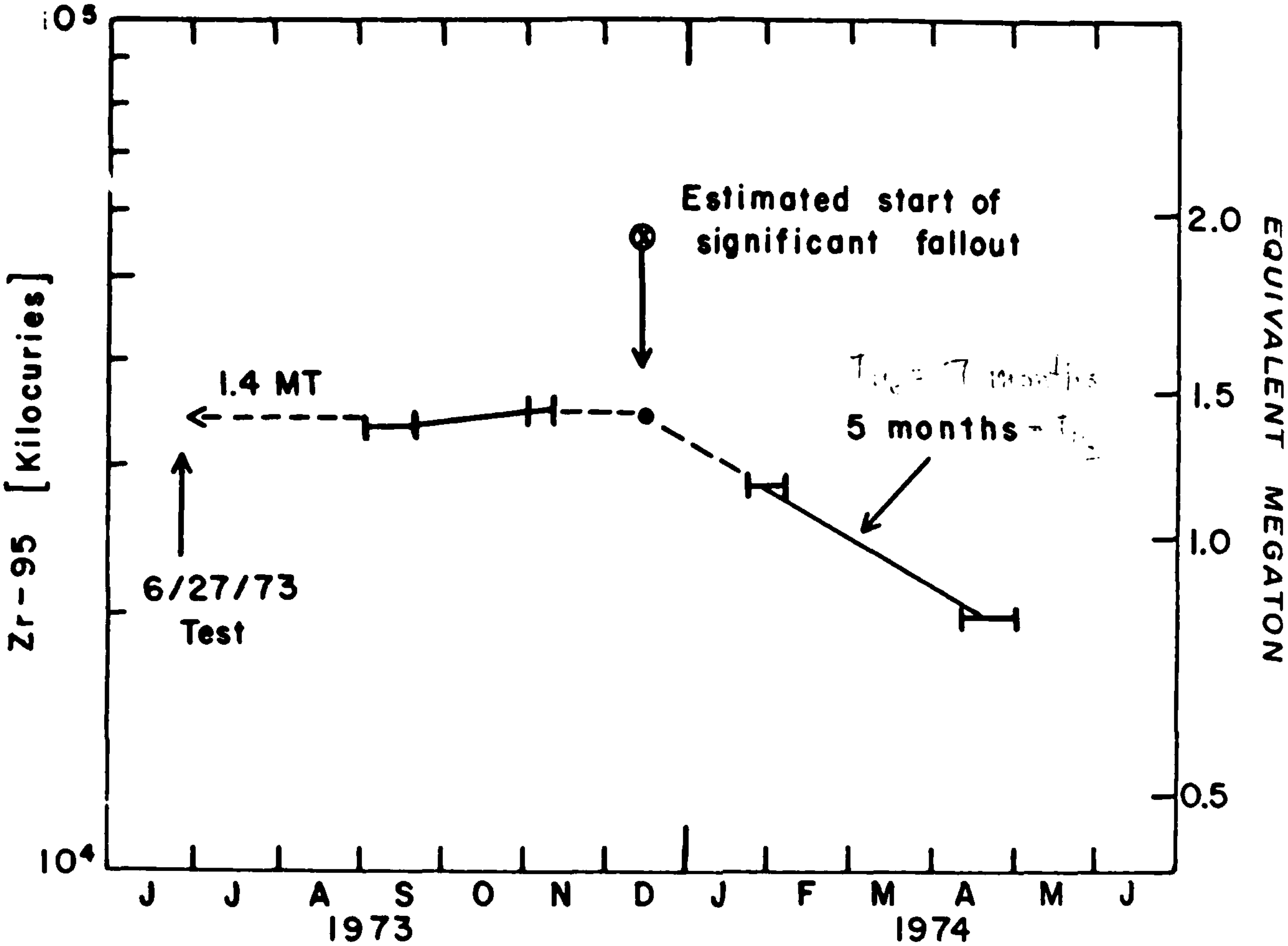
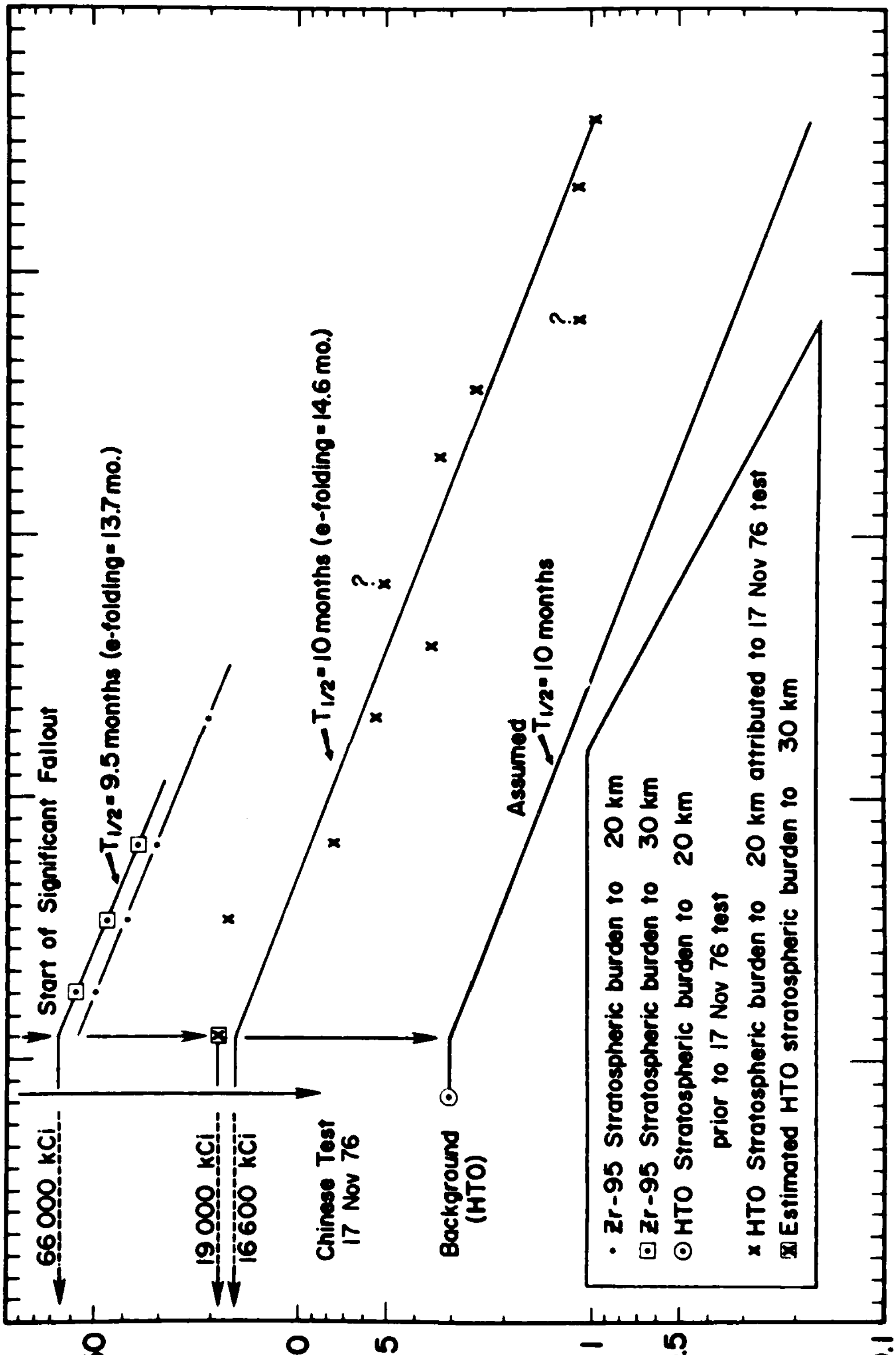


Fig. 9. Stratospheric equivalent half residence time of the Zr-95 burden for the Chinese test of June 27, 1973. Observed burdens are indicated by the short horizontal lines.



Mason et al (1982)

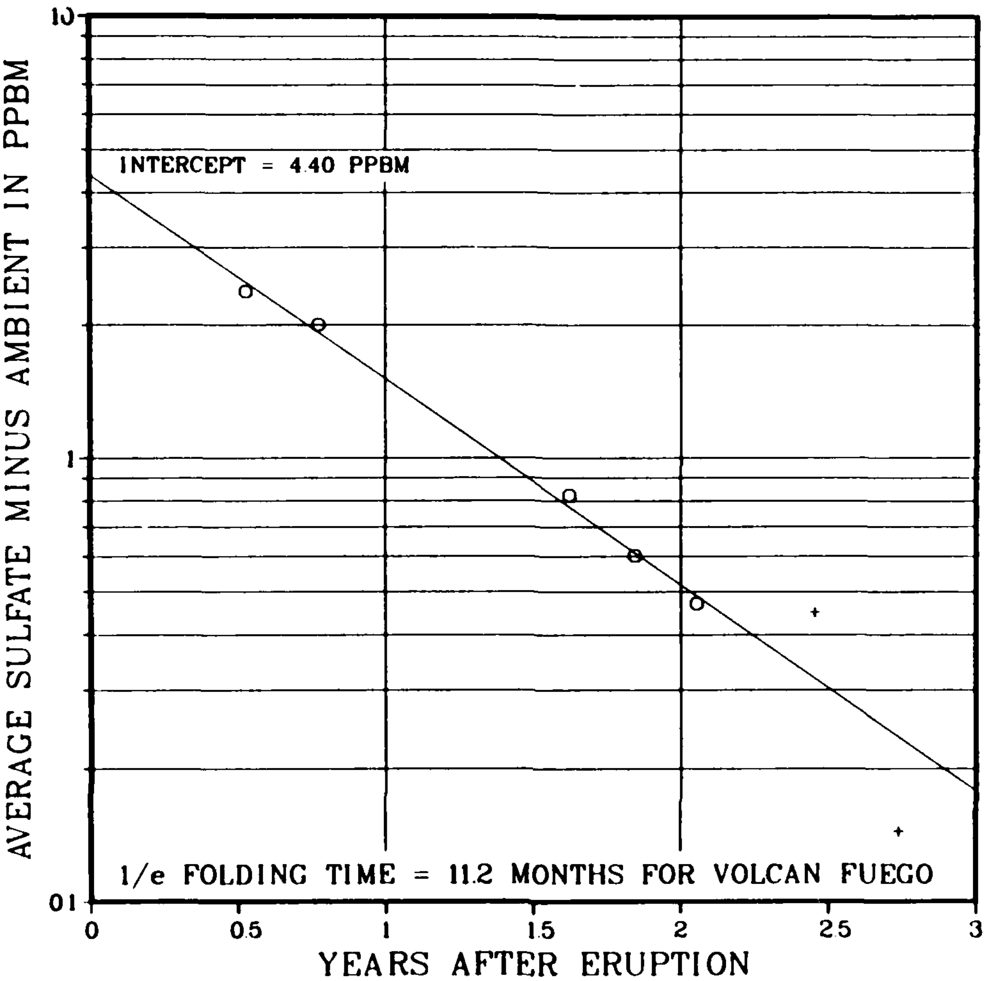


Fig. 35. Average 'stratospheric' sulfate concentration minus preceding 'ambient' concentration versus time from eruption to middate of sampling period. The least squares fitted *e*-fold removal rate for Fuego 1974 is 11.2 months. Only the first five data points, indicated by circles, were used to determine the least squares fit due to the low volcanic sulfate to 'ambient' sulfate ratio for the last two points. For Mount St. Helens the contribution of Sierra Negra preceding and subsequent Mount St. Helens, Gareloi, Alaid, and Pagan eruptions make an *e*-fold removal rate calculation meaningless.

STRATOSPHERIC RESIDENCE TIME

- Some disagreement among observations, but recent data indicates 1/e-times of 6-12 months in lower stratosphere

- Observations show comparable residence times in stratosphere for
  - gases (HTO)
  - radionuclides
  - volcanic sulfates

- Radionuclide data suggests no removal for a long period (3-6 months) following lower stratospheric injections

- Eulerian transport model gives 1/e-times in lower stratosphere of 2-3 months

HEAVY METHANE EXPERIMENTS

- Three releases of 1 kg CD_4 in midtroposphere near 55S, 165E (January, June, October 1984)

- Precisely characterized source: time, place, altitude, amount. Inert tracer.

- Samples collected
  - on airplane flights between Antarctic stations, and to/from New Zealand (1 hour averages)
  - at surface stations (3 day averages)
  - for 60 days after release

- Detection limit ~ 10^{-17} g CD_4 / g air

- Samples above limit found out to 20 days (longest data series for a tropospheric tracer?)

- Principal shortcoming: limited sampling precludes complete picture of large-scale distribution. Modeling comparisons may help.

MODEL VS OBSERVATIONS

Eulerian transport model

- gives reasonable qualitative tracer behavior
- but concentration is diluted too rapidly

Possible explanations

- Inherent inability of Eulerian model to simulate "point source"

- Dispersed source at t=0 may make simulated tracer prematurely susceptible to dispersal by large-scale eddies

- Excessive lateral diffusion of Eulerian tracer distribution stretched by "geostrophic turbulence"

GEOSTROPHIC TURBULENCE

- Nonlinear large-scale eddies in rotating stratified fluid

- Essentially two-dimensional (D << L)

- Energy transfer to larger scales causes stretching and deformation of tracer distribution without mixing (unlike small-scale 3-D turbulence)

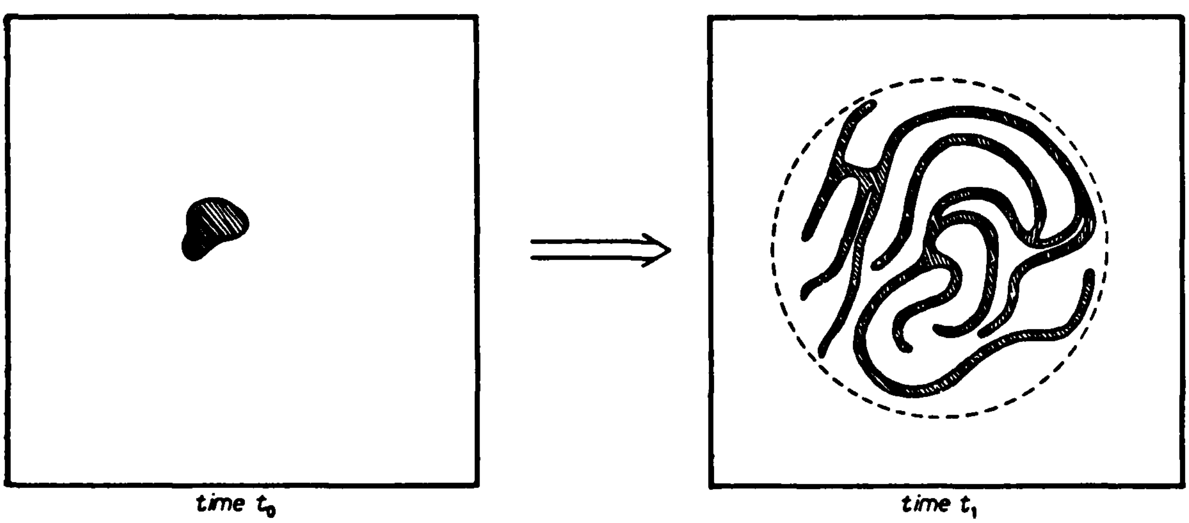
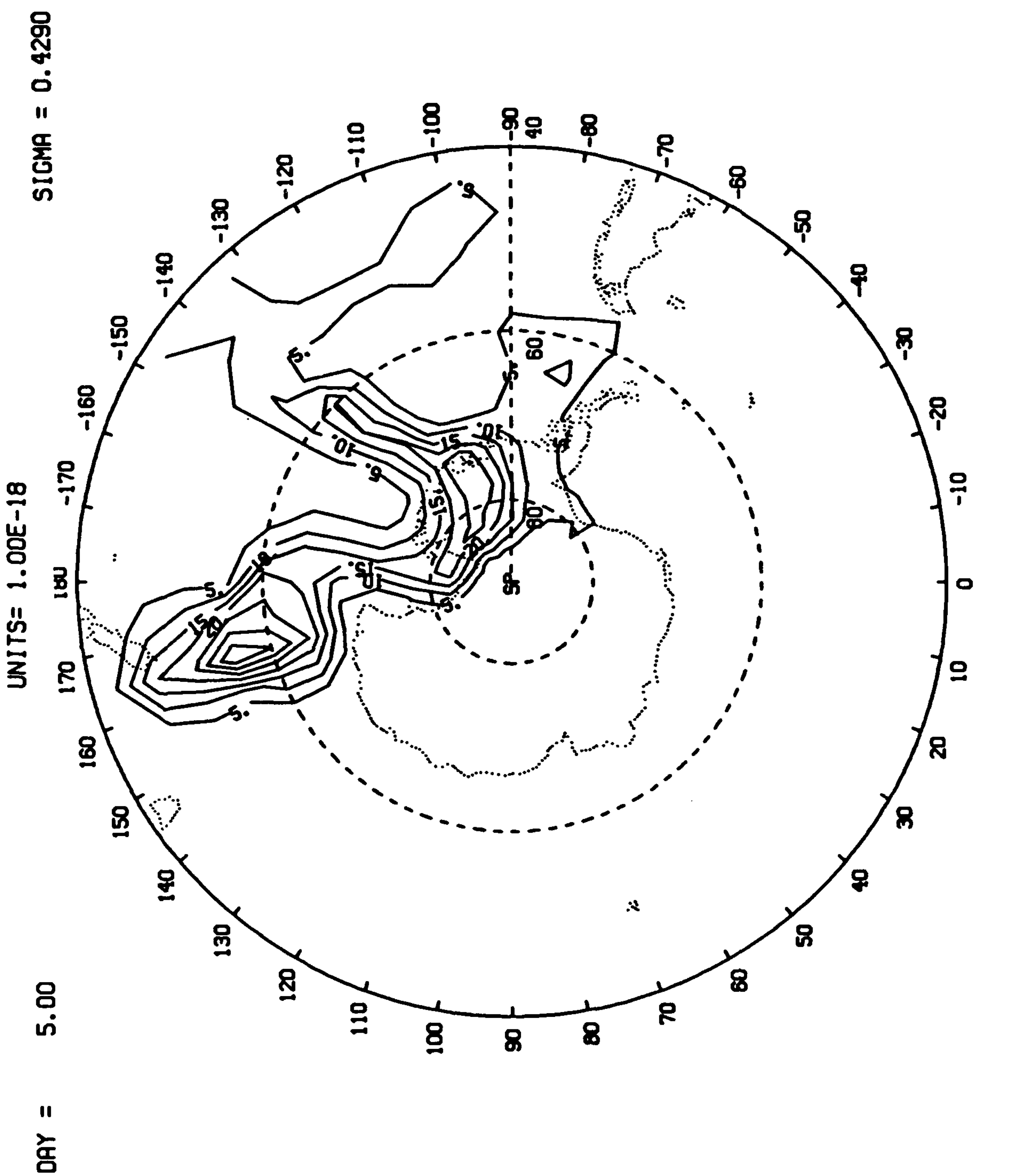


Fig. 4. – Mixing in a two-dimensional phase space.



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GEOSTROPHIC TURBULENCE

- Growth to a rather large scale is required before deformation becomes rapid and pronounced.

- However, if start with large distributed source, deformation can begin immediately.

- For point source, time required for distribution to reach the critical scale depends on small-scale processes that may not be well represented by coarse resolution of GCM.

LAGRANGIAN TRACER MODEL

Use to study

- Dispersal from "point source" release

- Relative importance for large-scale mixing of

  - particle distribution deformation (stretching) by geostrophic turbulence

  - small-scale motions (unresolved by GCM) that cause spreading relative to "stretched" distribution

  - shearing of distribution (in the vertical) by vertical gradients of the horizontal winds

  - initial vertical and horizontal extent of particle distribution ("exposure" to gradients in wind)

- Long stratospheric residence times

CONCLUSIONS

Eulerian transport model

- is suitable for <u>distributed</u> sources
- captures basic features of Arctic haze
- simulated poleward migration from midlatitudes agrees with observations
- displays deformation of tracer distribution characteristic of geostrophic turbulence
- but coarse resolution causes too rapid dispersal compared to point-source data
- underestimates aerosol residence time in lower stratosphere (recent measurements give 6-12 months or longer)

• Most promising analogues for quantitative transport comparisons:
  - *heavy methane (troposphere)*
  - *radionuclides (stratosphere)*

The Hydrological Response to Summertime Injections of Smoke into the Atmosphere

Steven J. Ghan, Michael C. MacCracken, John J. Walton

Lawrence Livermore National Laboratory

January 1986

Studies of the summertime temperature response to varying amounts of smoke indicate that sharp cooling does not occur until sufficient smoke has been injected to convectively decouple the surface and troposphere. For smaller amounts of smoke, relatively small temperature changes may result, and even modest warming may occur as a result of a reduced planetary albedo. Although convective processes may still be tieing the surface and troposphere together for these smaller smoke amounts, the rate of convection drops in direct proportion to solar absorption by the smoke particles. Thus, convection is suppressed for small smoke loadings as well as large ones. Because much of the normal summertime precipitation is convective in nature, we conclude that significant drought-like reductions in land precipitation are possible, even for summertime tropospheric smoke injections small enough to cause only small temperature changes, or even a surface warming. Results from experiments with a tropospheric general circulation model under a variety of summertime smoke injections are presented in support of this conclusion.

The Fate of Smoke: Sensitivity Studies with a Global-Scale Atmospheric Model

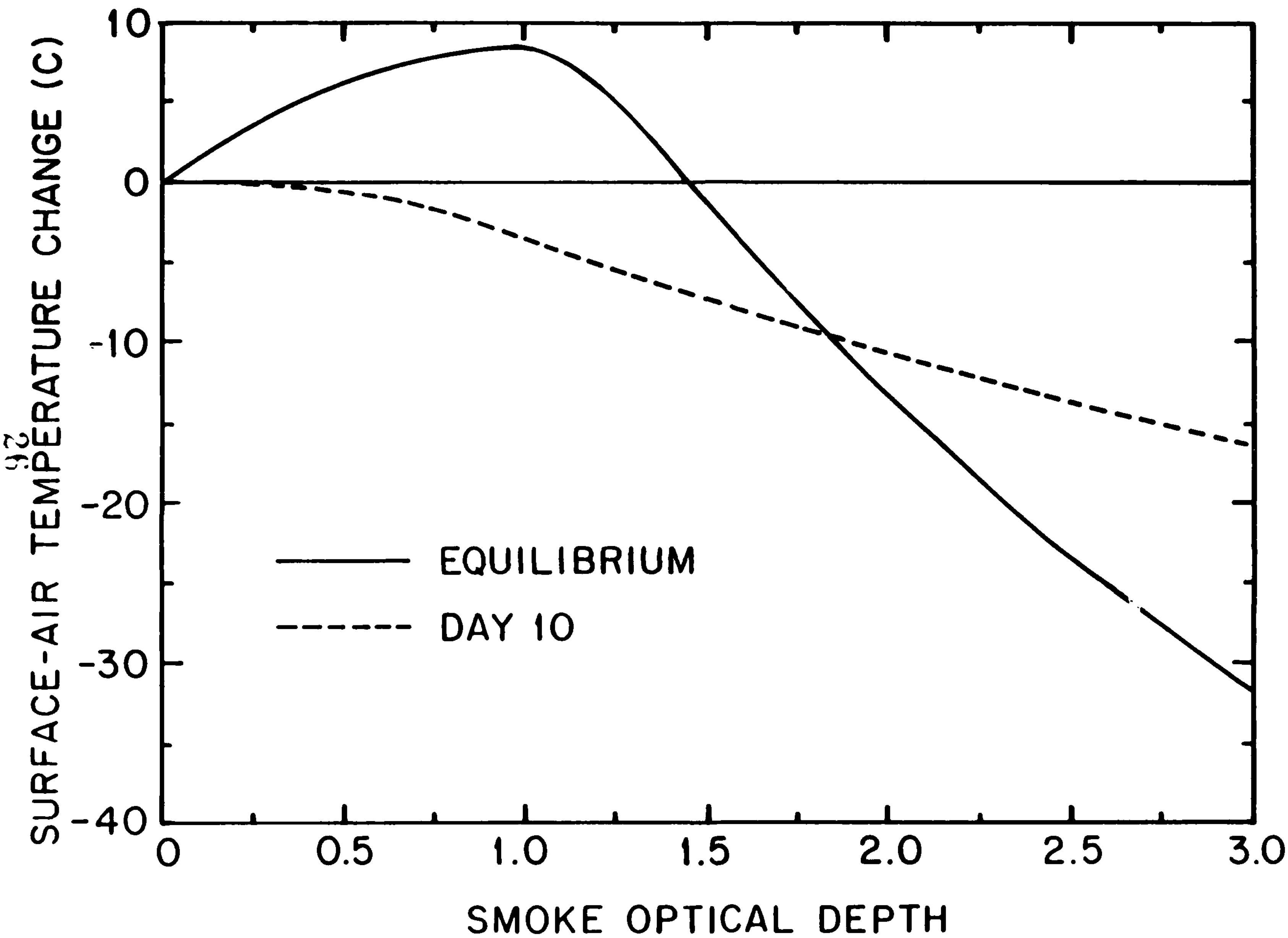
Steven J. Ghan, Michael C. MacCracken, John J. Walton

Lawrence Livermore National Laboratory

January 1986

The relative importance of several smoke removal processes has been considered using a tropospheric general circulation model. Smoke particles have been divided into two categories: those smaller and those larger than one micron in diameter. Removal processes for each aerosol include precipitation scavenging and dry deposition. Small particles can coagulate to become larger particles. Scavenging is found to be the most efficient removal mechanism for the large particles. For sub-micron particles, the scavenging rate is based on removal rates inferred for Arctic soot, primarily by ice processes. For these small particles, coagulation is most important at high concentrations, while scavenging and dry deposition are comparably important at lower concentrations, depending on the specified parameter values. The lifetime of the smaller particles is significantly longer than for the large particles, both because of less efficient scavenging and because of a lower dry deposition velocity. The importance of accounting for sub-grid scale patchiness of precipitation in reducing effective scavenging, and the smoke-induced stabilization of the planetary boundary layer in reducing dry deposition are assessed.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.



SURFACE-AIR TEMPERATURE CHANGE (C)
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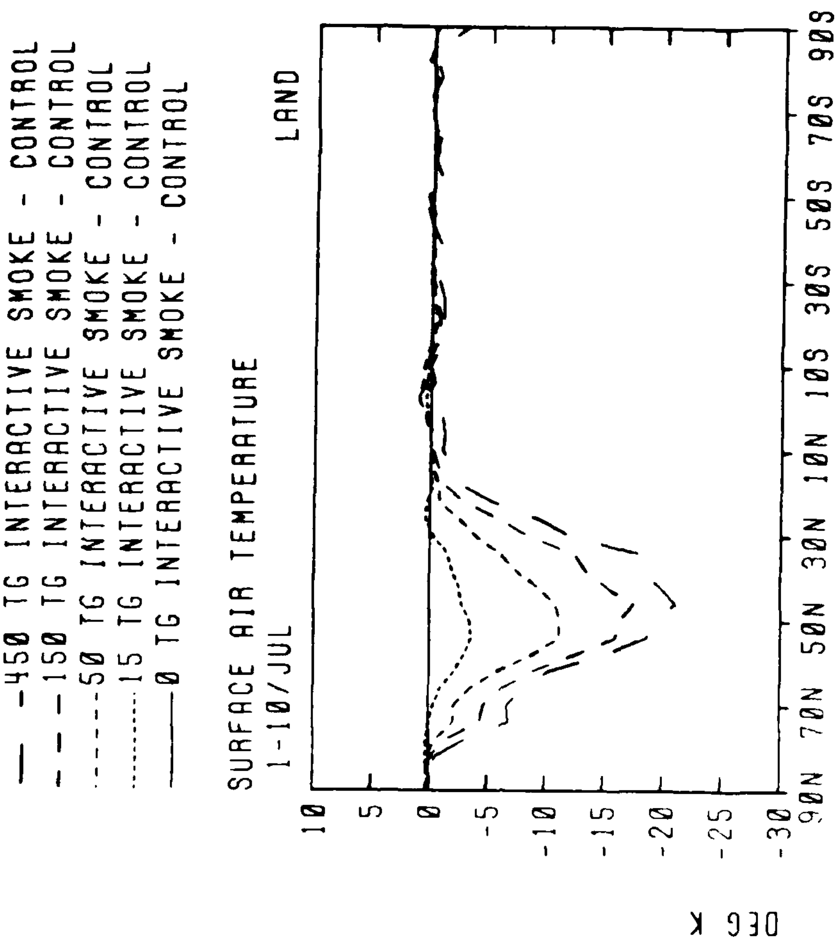
3.0
SMOKE OPTICAL DEPTH
EQUILIBRIUM
DAY 10

Fig. 8



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150 TG INTERACTIVE SMOKE - CONTROL
50 TG INTERACTIVE SMOKE - CONTROL
15 TG INTERACTIVE SMOKE - CONTROL
0 TG INTERACTIVE SMOKE - CONTROL
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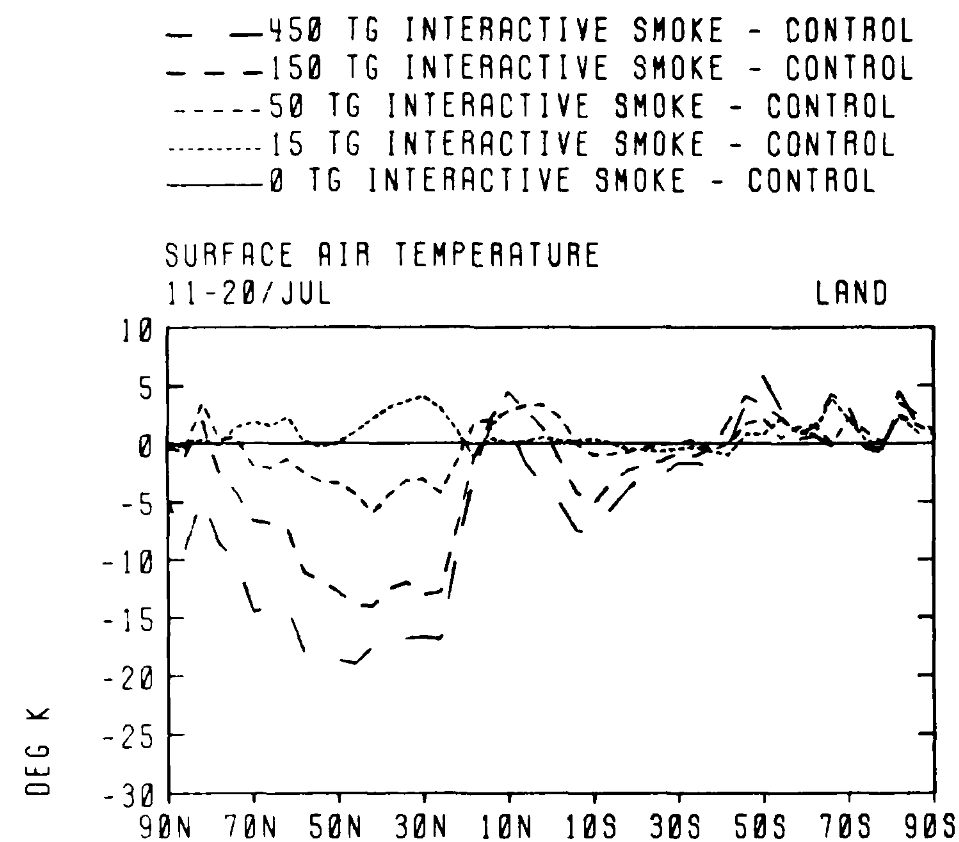

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0 TG INTERACTIVE SMOKE - CONTROL
SURFACE AIR TEMPERATURE
11-20/JUL
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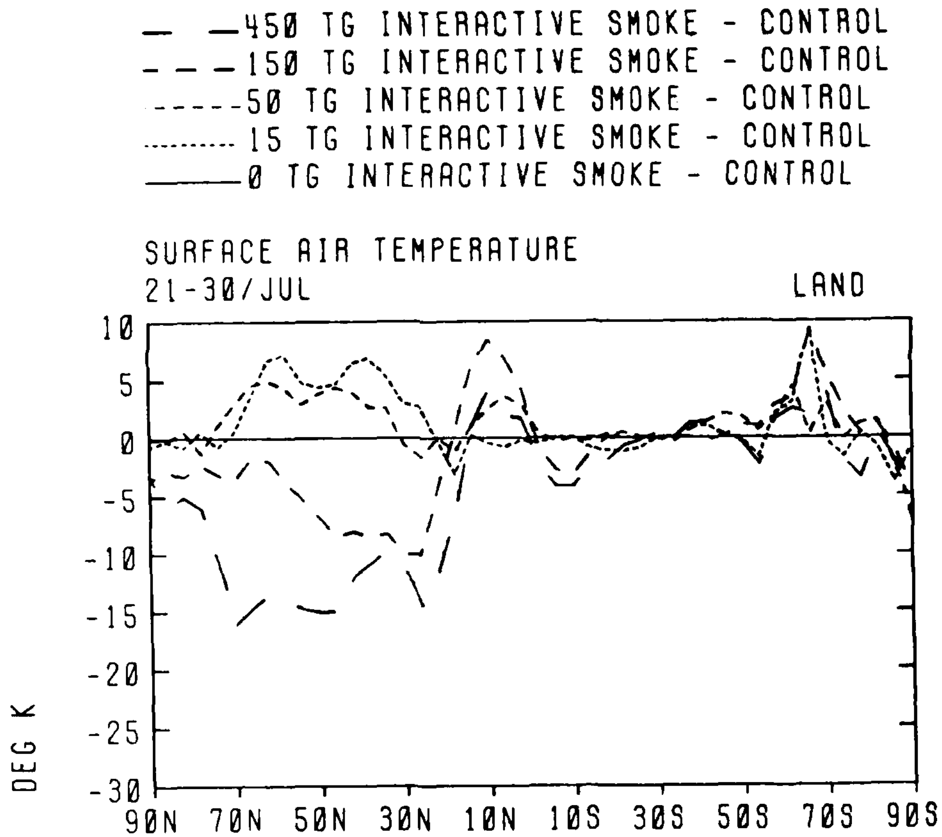
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SURFACE AIR TEMPERATURE
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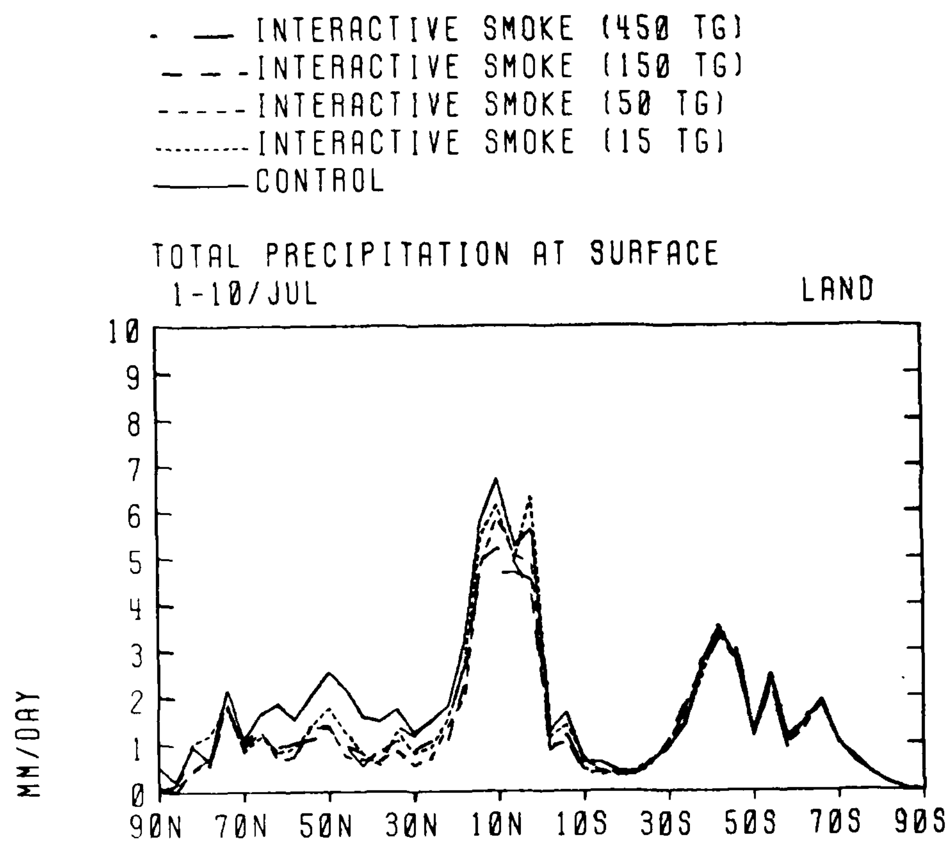
INTERACTIVE SMOKE (450 TG)
INTERACTIVE SMOKE (150 TG)
INTERACTIVE SMOKE (50 TG)
INTERACTIVE SMOKE (15 TG)
CONTROL
TOTAL PRECIPITATION AT SURFACE
1-10/JUL
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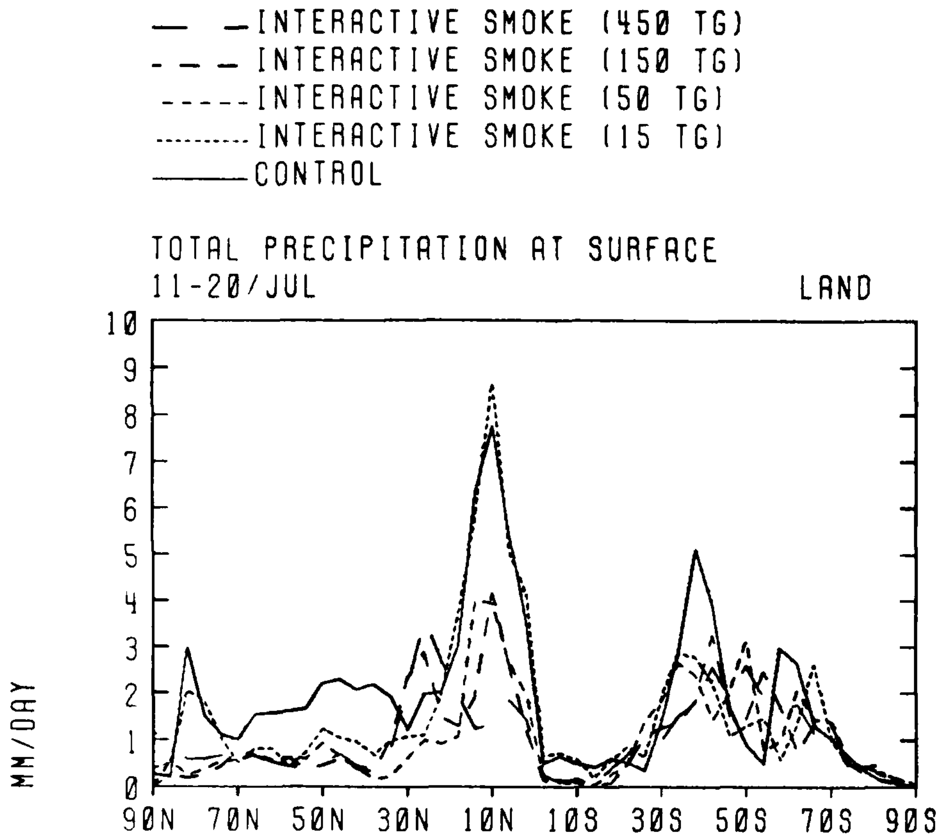

INTERACTIVE SMOKE (450 TG)
INTERACTIVE SMOKE (150 TG)
INTERACTIVE SMOKE (50 TG)
INTERACTIVE SMOKE (15 TG)
CONTROL
TOTAL PRECIPITATION AT SURFACE
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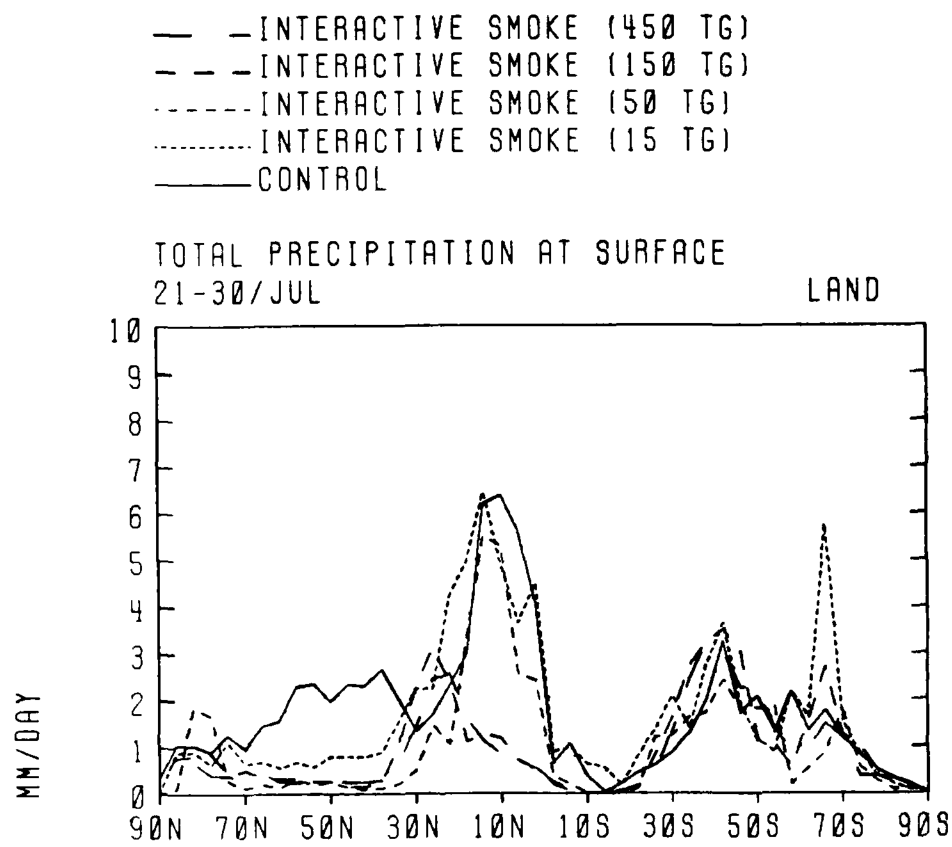
90N 70N 50N 30N 10N 10S 30S 50S 70S 90S



INTERACTIVE SMOKE (450 TG)
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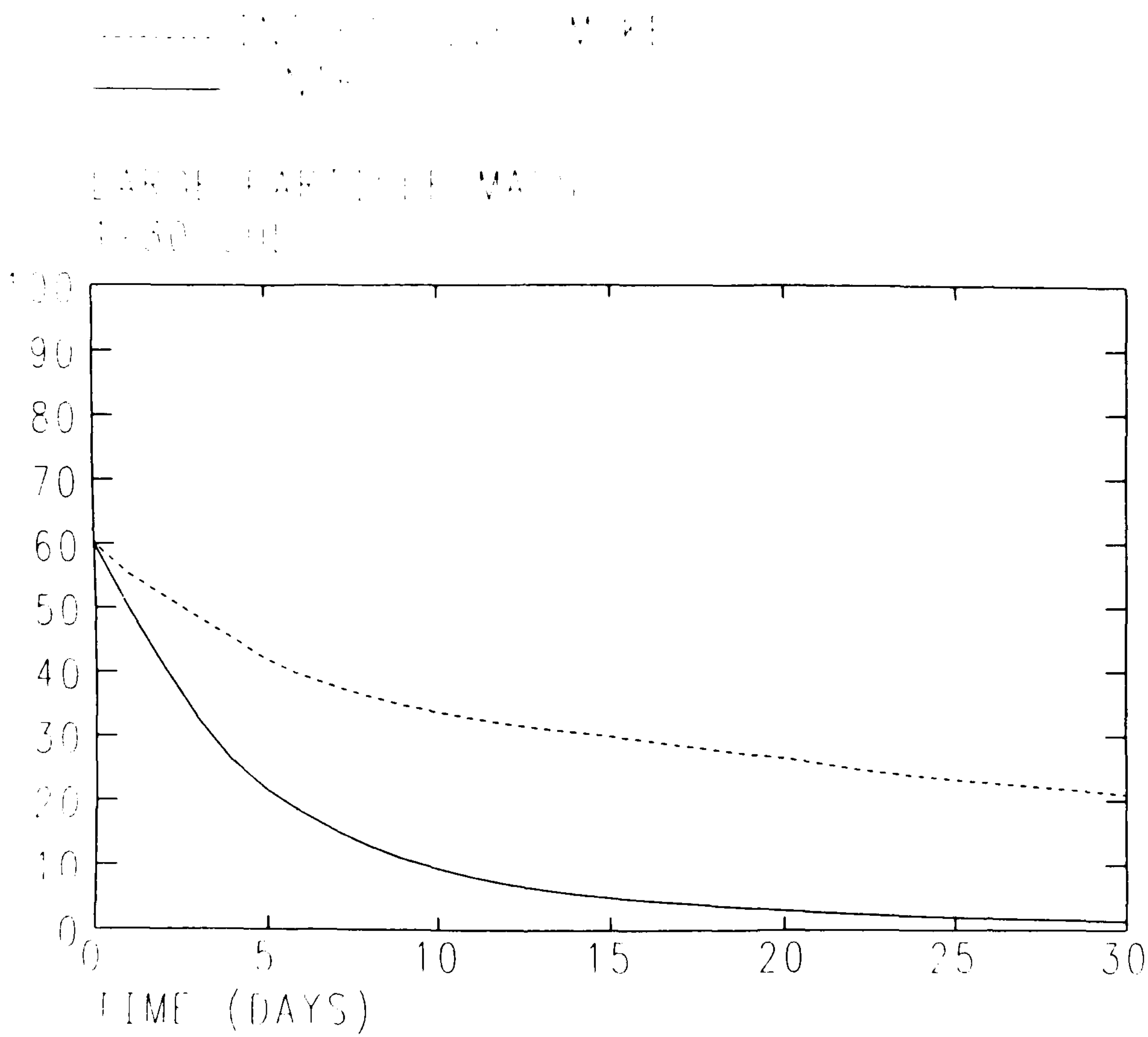


Figure 16. The globally integrated mass of large smoke particles for days 1-30 of a control (passive smoke) simulation and following a 150 Tg July injection of smoke.

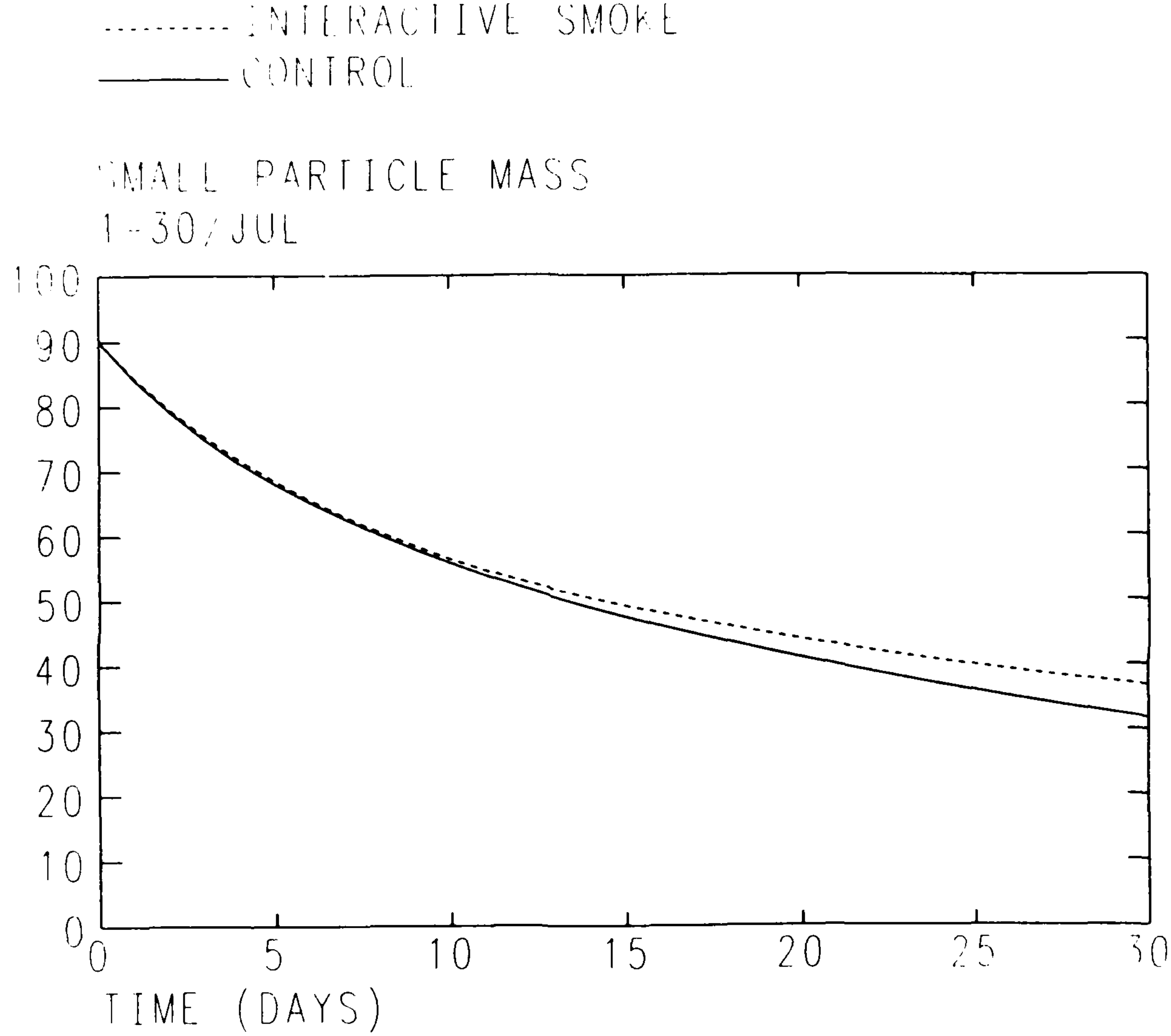


Figure 18. As in Fig. 16 but for small smoke particles.

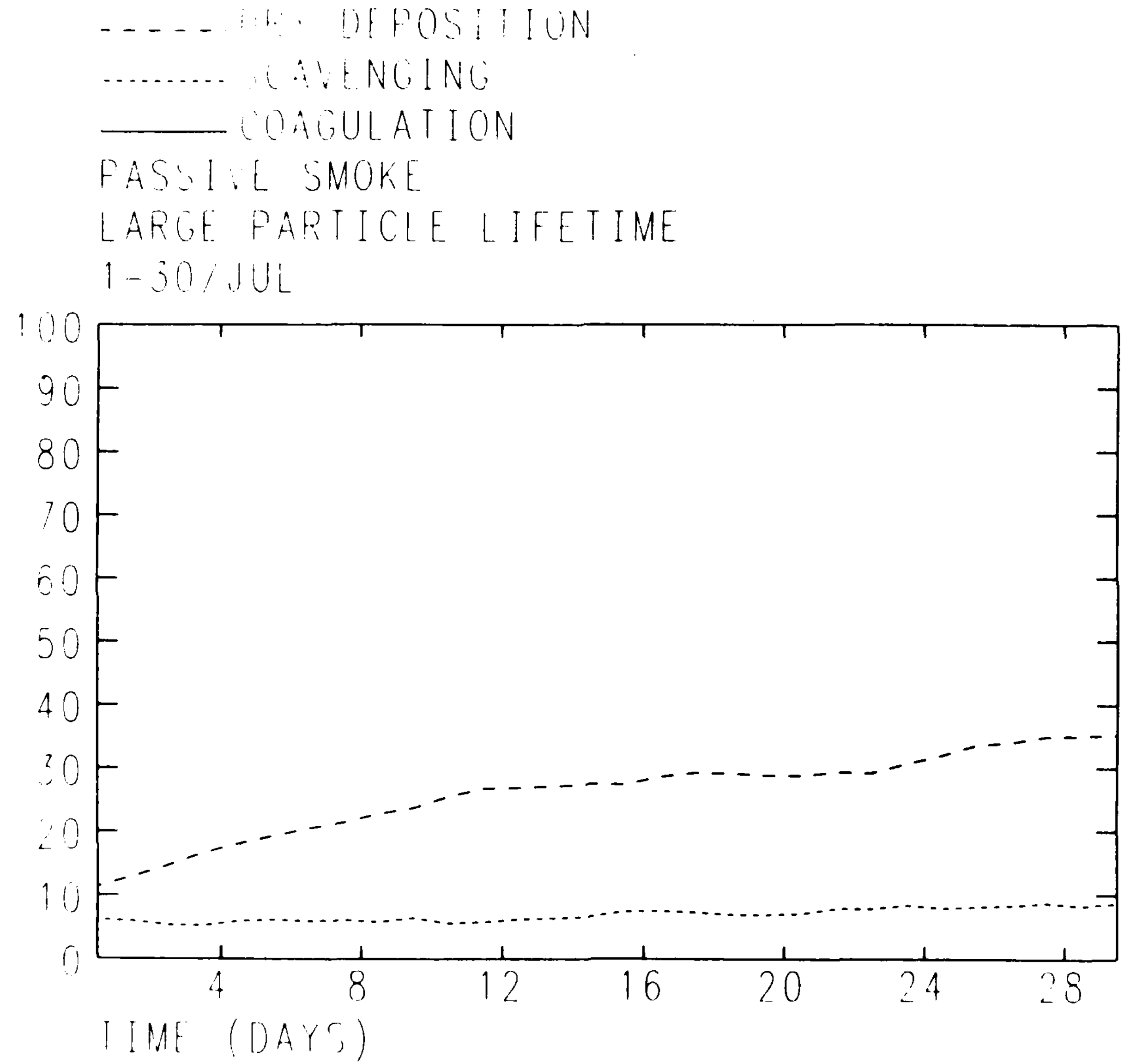


Figure 22. Lifetimes of large smoke particles for a control simulation, with removal by dry deposition, precipitation scavenging, and coagulation, individually. Note that, for large particles the coagulation lifetime is not defined.

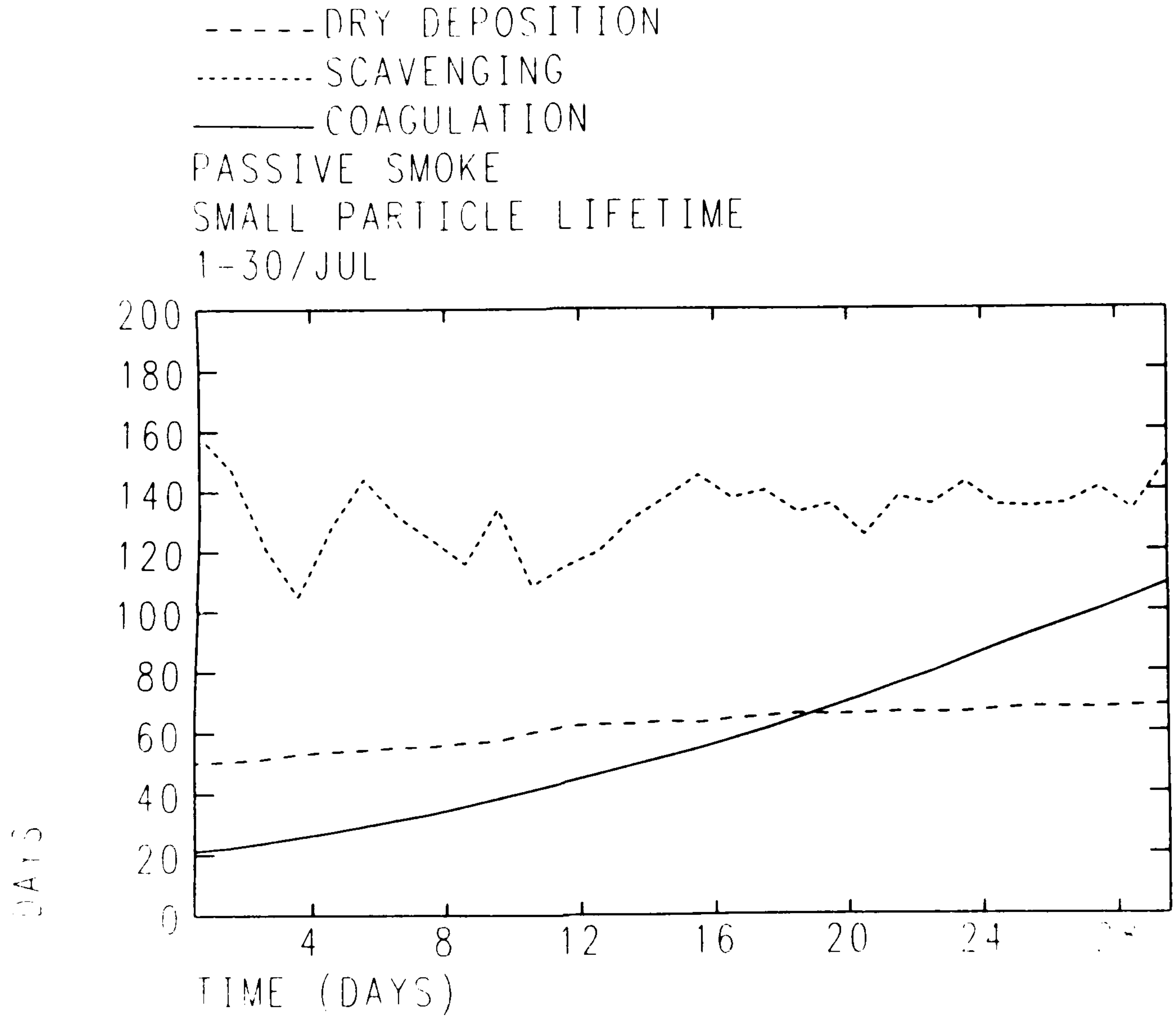


Figure 23. As in Fig. 22 but for small smoke particles.

Scavenging Coefficients (cm^{-1})

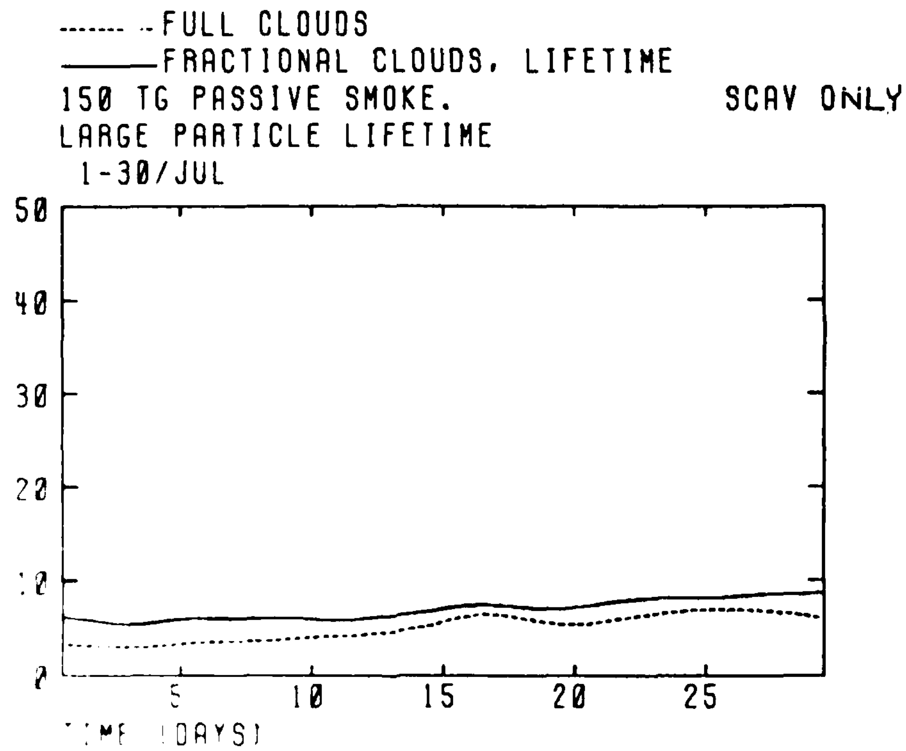
	$< 1\ \mu m$	$> 1\ \mu m$
Convective Precipitation	0.07	3
Stratiform Precipitation	0.2	8

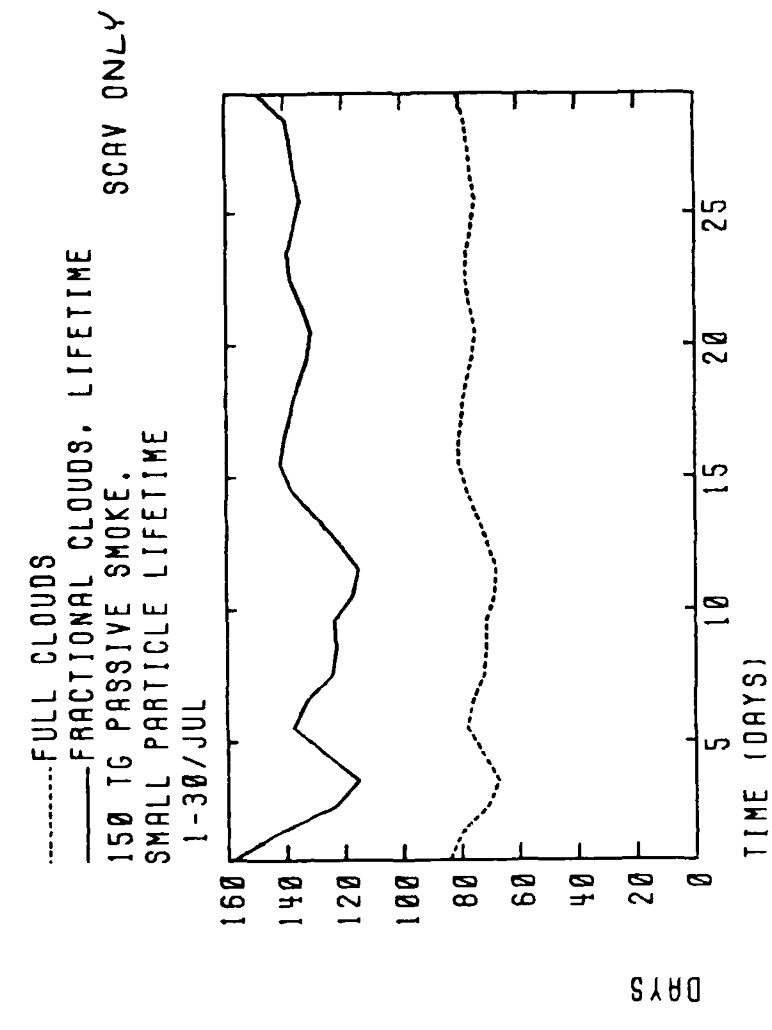
Arctic Aerosols: ~ 1

Malone et al.: ~ 14

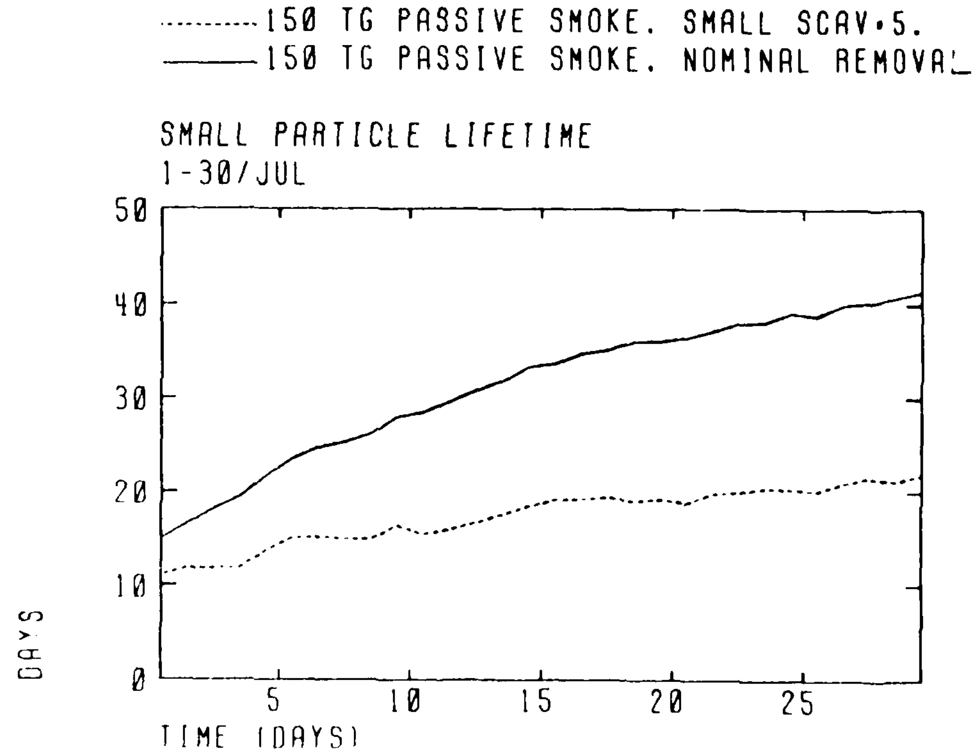
Cloud Parameters

	Fractional Area	Cloud Lifetime
Convective	0.2	6 hr
Stratiform	0.75	18 hr

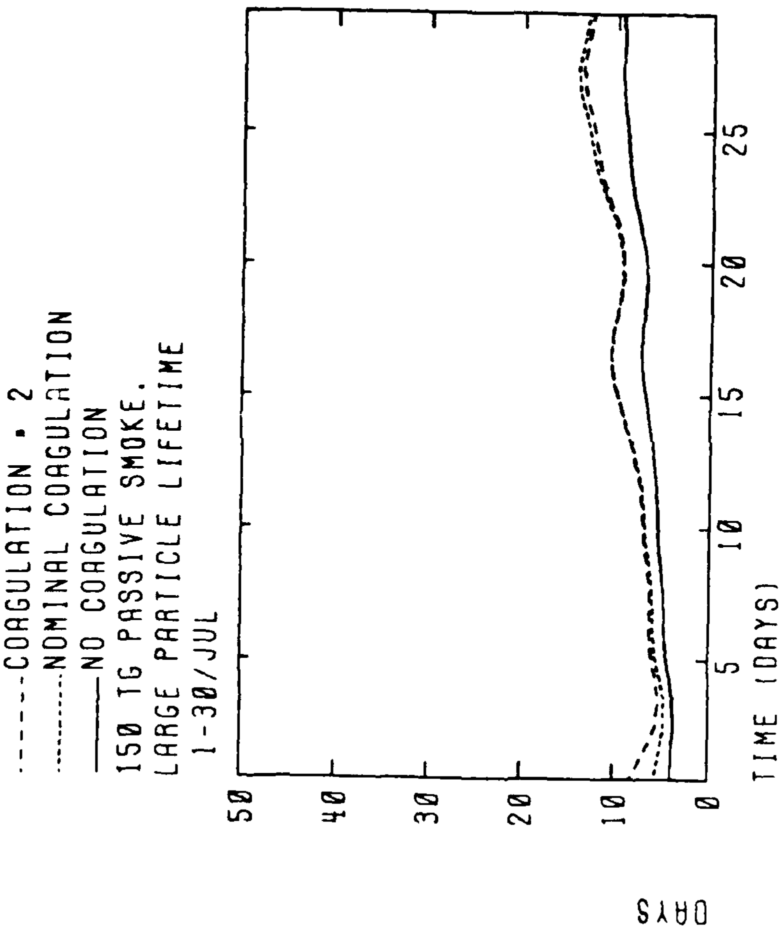

FULL CLOUDS
FRACTIONAL CLOUDS, LIFETIME
150 TG PASSIVE SMOKE.
SCAV ONLY
LARGE PARTICLE LIFETIME
1-30/JUL
50
40
30
20
0
5
10
15
20
25
(DAYS)

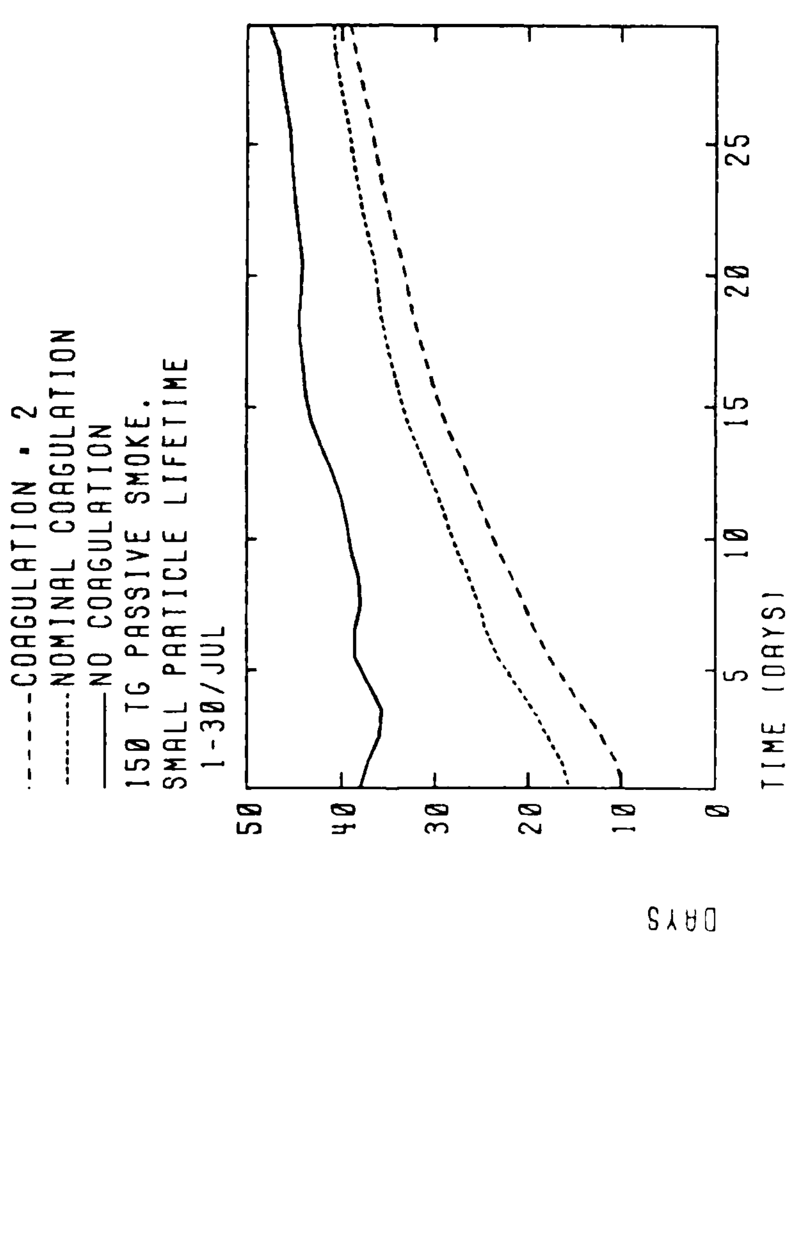


FULL CLOUDS
FRACTIONAL CLOUDS, LIFETIME
150 TG PASSIVE SMOKE,
SMALL PARTICLE LIFETIME
1-30/JUL
SCAV ONLY
DAYS
160
140
120
100
80
60
40
20
0
5
10
15
20
25
TIME (DAYS)

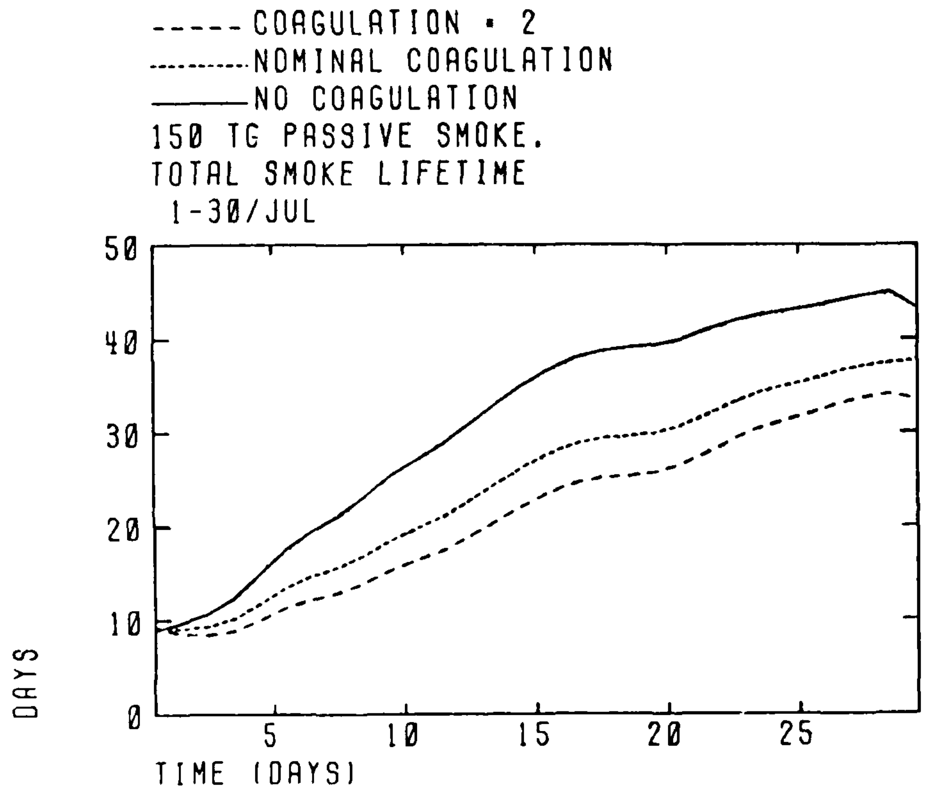


150 TG PASSIVE SMOKE. SMALL SCAV•5.
150 TG PASSIVE SMOKE. NOMINAL REMOVAL
SMALL PARTICLE LIFETIME
1-30/JUL
DAYS
50
40
30
20
10
0
5
10
15
20
25
TIME (DAYS)


COAGULATION • 2
NOMINAL COAGULATION
NO COAGULATION
150 TG PASSIVE SMOKE,
LARGE PARTICLE LIFETIME
1-30/JUL
DAYS
TIME (DAYS)
0
10
20
30
40
50
5
15
25



COAGULATION * 2
NOMINAL COAGULATION
NO COAGULATION
150 TG PASSIVE SMOKE.
SMALL PARTICLE LIFETIME
1-30/JUL
50
40
30
20
10
0
DAYS
5
10
15
20
25
TIME (DAYS)

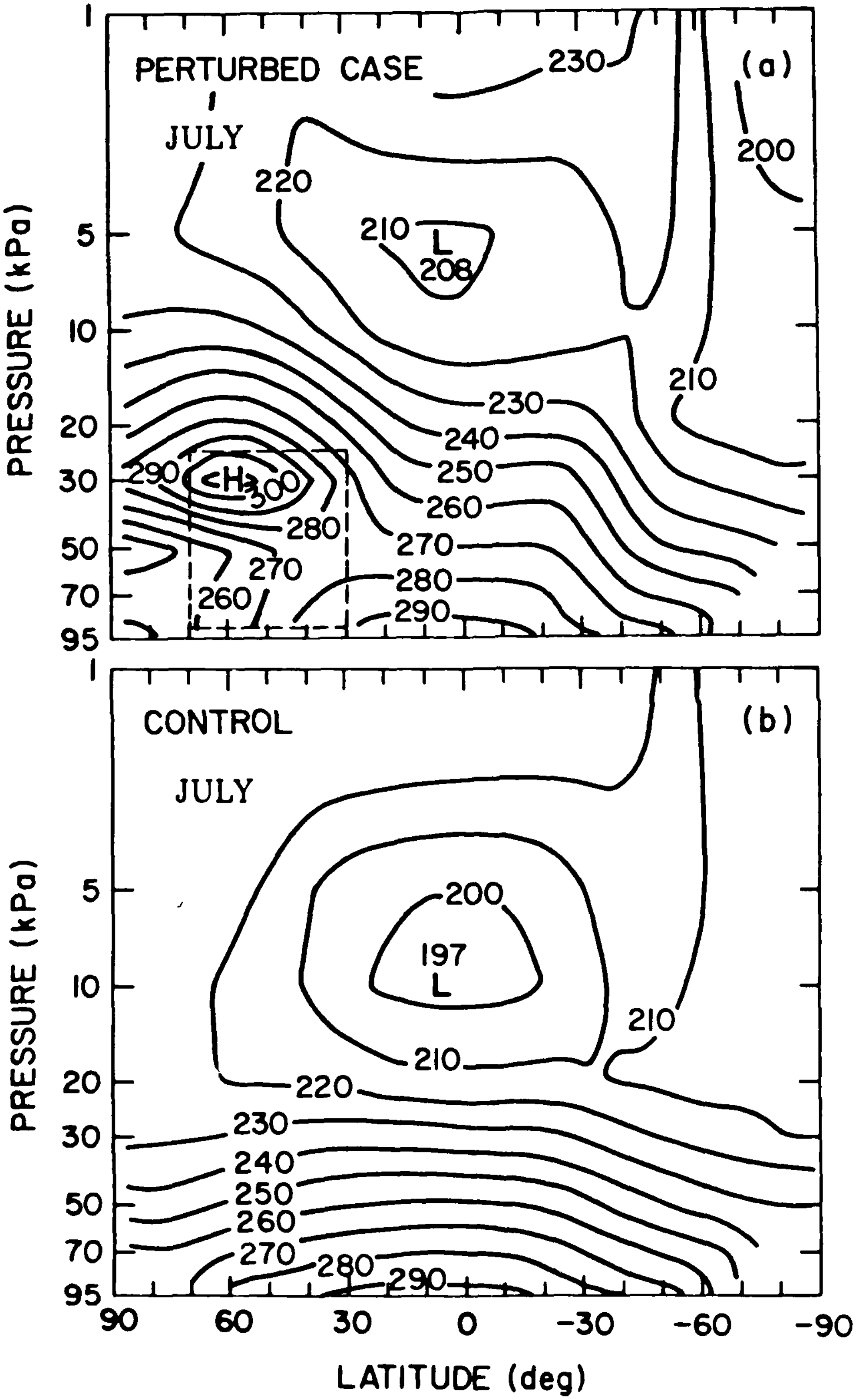


----- COAGULATION * 2
.... NOMINAL COAGULATION
—— NO COAGULATION
150 TG PASSIVE SMOKE.
TOTAL SMOKE LIFETIME
1-30/JUL
DAYS
0
10
20
30
40
50
5
10
15
20
25
TIME (DAYS)

Global Modeling: The Rationale,
Progress and Plans for Research at NCAR

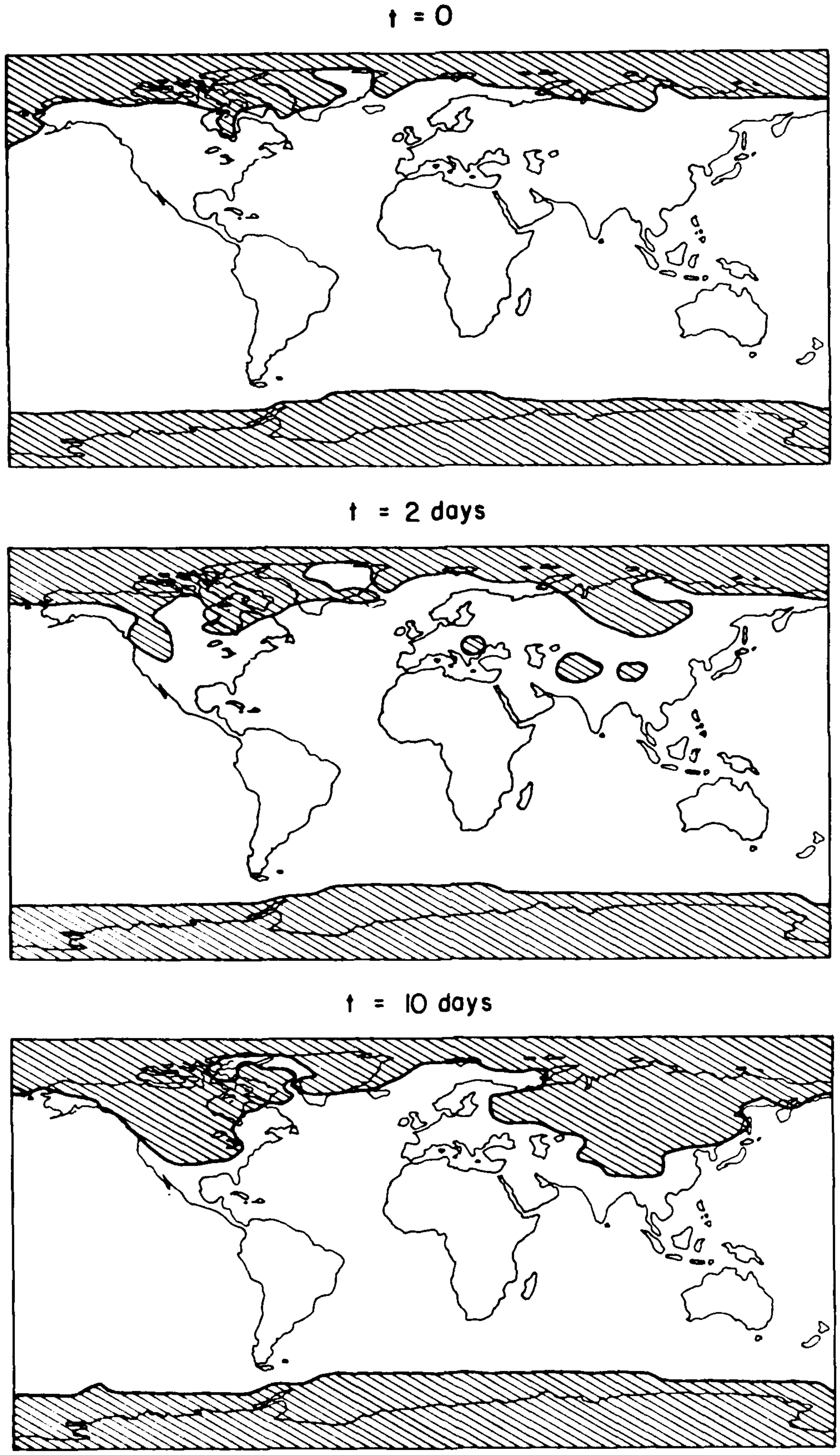
Dr. Stephen H. Schneider
National Center for Atmospheric Research

ZONALLY AVERAGED TEMPERATURE (Kelvin)



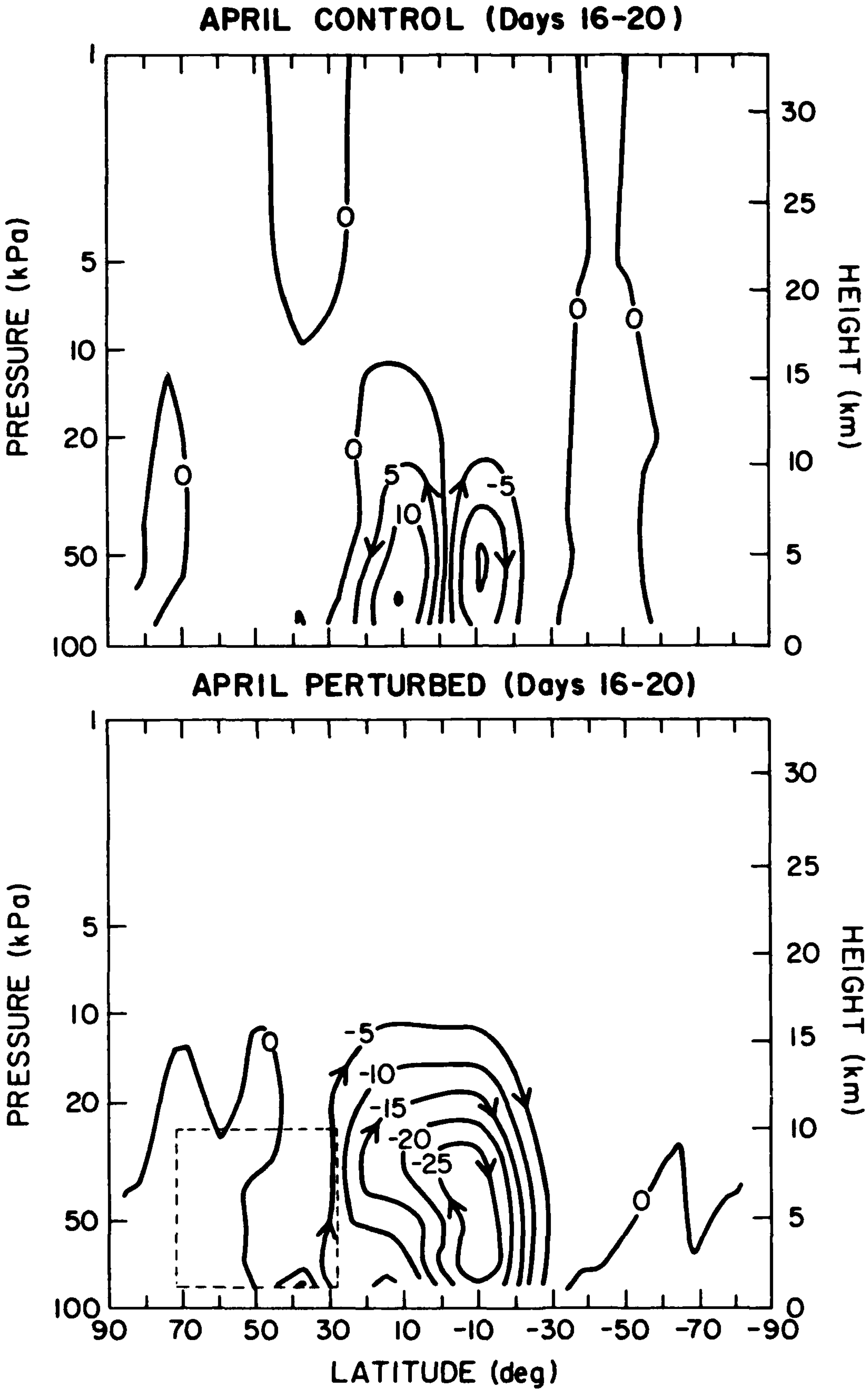
NCAR (1983)

SURFACE TEMPERATURE (Shaded Below Freezing)

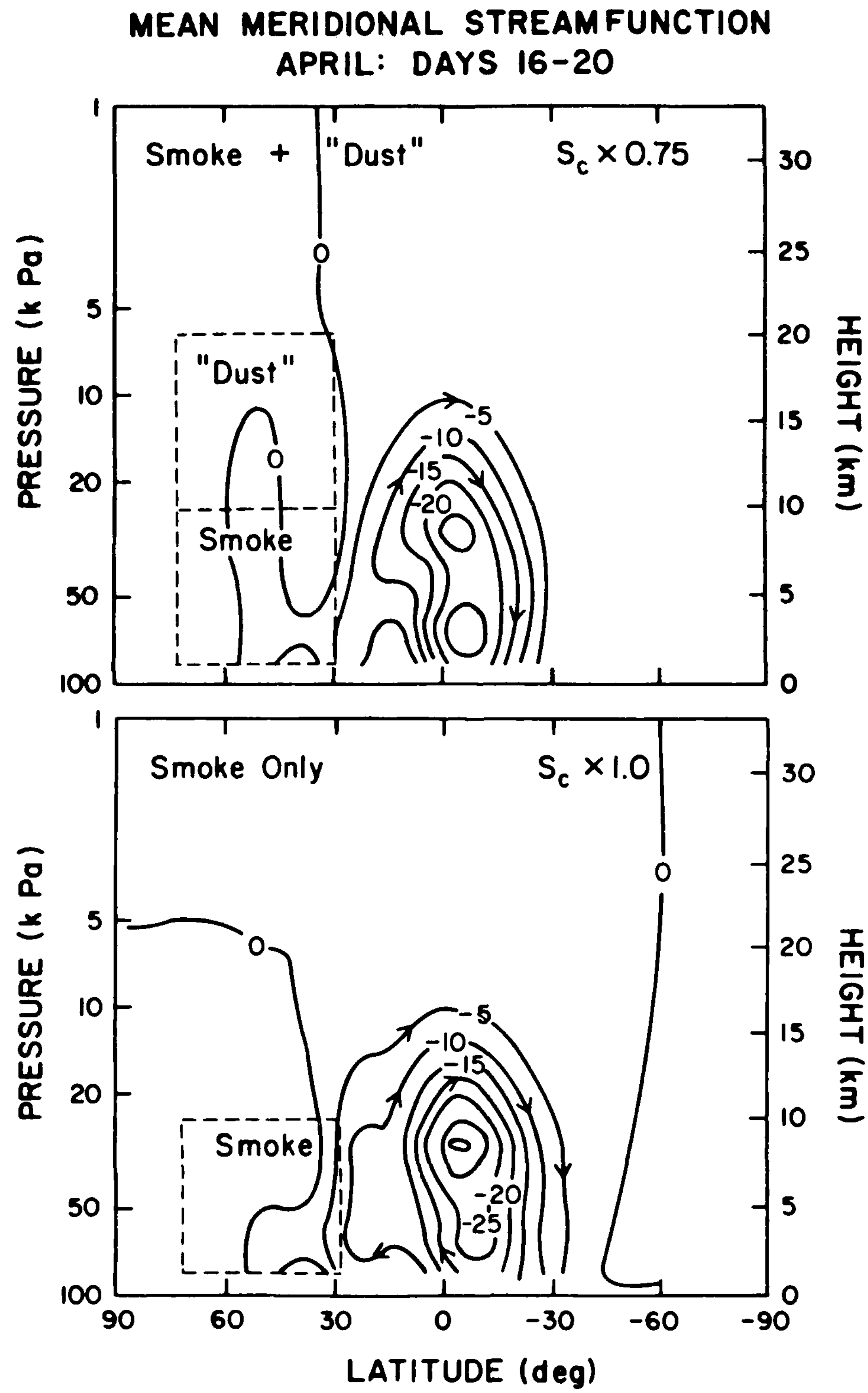


NCAR (1983)

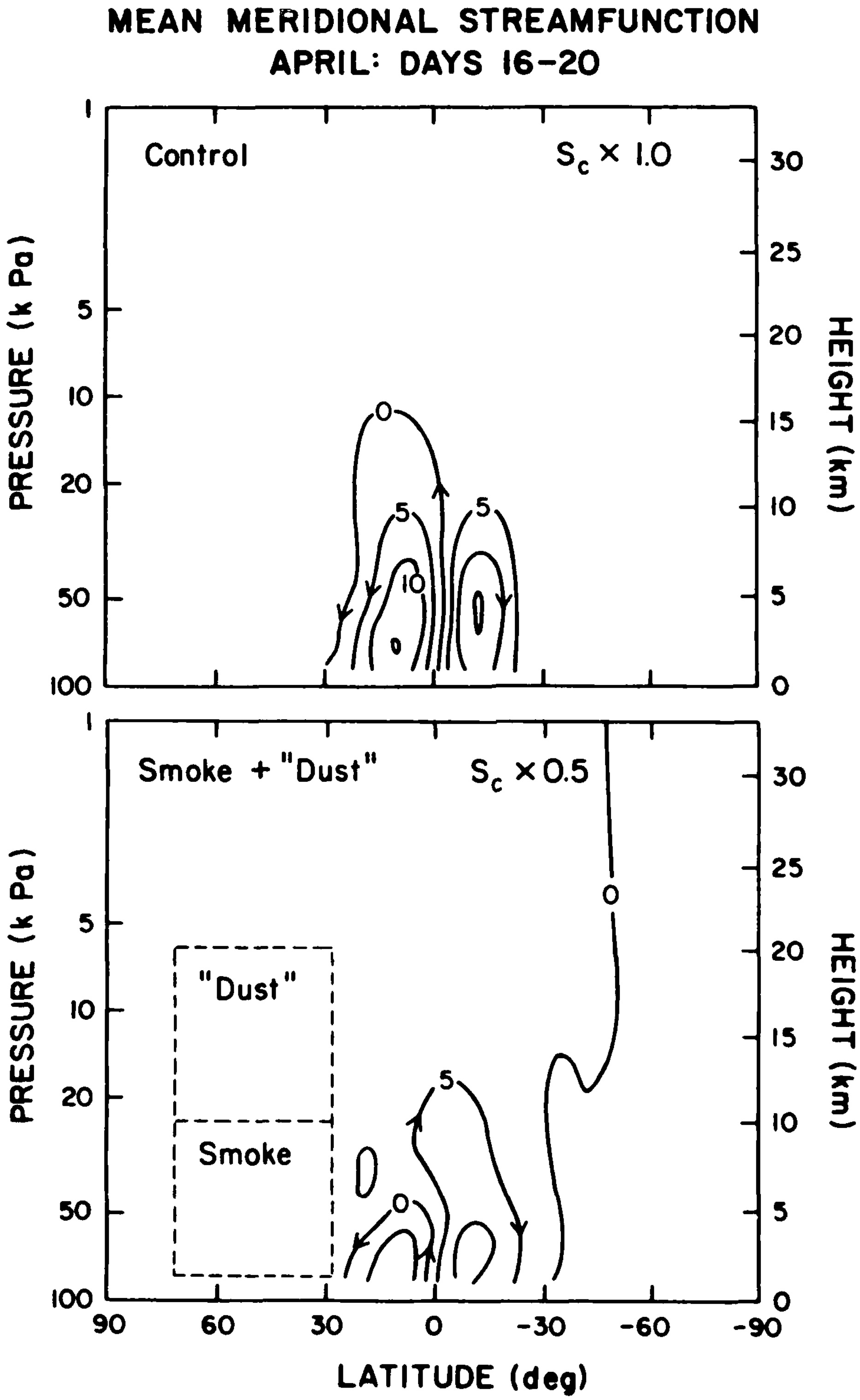
MERIDIONAL CIRCULATION



NCAR (1983)


MEAN MERIDIONAL STREAMFUNCTION
APRIL: DAYS 16-20
Smoke + "Dust"
$S_c \times 0.75$
"Dust"
Smoke
Smoke Only
$S_c \times 1.0$
PRESSURE (k Pa)
HEIGHT (km)
LATITUDE (deg)
1
5
10
20
50
100
30
25
20
15
10
5
0
90
60
30
0
-30
-60
-90
-5
-10
-15
-20
-25

NCAR (1984)


MEAN MERIDIONAL STREAMFUNCTION
APRIL: DAYS 16-20
Control
$S_c \times 1.0$
Smoke + "Dust"
$S_c \times 0.5$
"Dust"
Smoke
PRESSURE (k Pa)
HEIGHT (km)
LATITUDE (deg)
1
5
10
20
50
100
0
5
10
15
20
25
30
90
60
30
0
-30
-60
-90

NCAR (1984)

Physical Processes to Incorporate or Improve In Three-Dimensional Models For Nuclear Winter Research

Radiative Transfer

- Infrared effects of smoke and dust
- Scattering of solar radiation by smoke and dust
- Refined optical properties of smoke and dust (size distribution, refractive indices, non-sphericity)

Surface Temperature Calculation

- Diurnal cycle of heating
- Explicit parameterization of soil heat storage
- Vegetation effects

Planetary Boundary Layer Representation

- Stability dependent vertical mixing
- Inclusion of low level clouds and fog

NCAR (1984)

- 2 -

Physical Processes to Incorporate or Improve In Three-Dimensional Models For Nuclear Winter Research

Sub-grid Scale Vertical Transport

- Internally consistent convective transport methods for smoke and dust, as well as heat and moisture
- Stability dependent "background" vertical diffusion

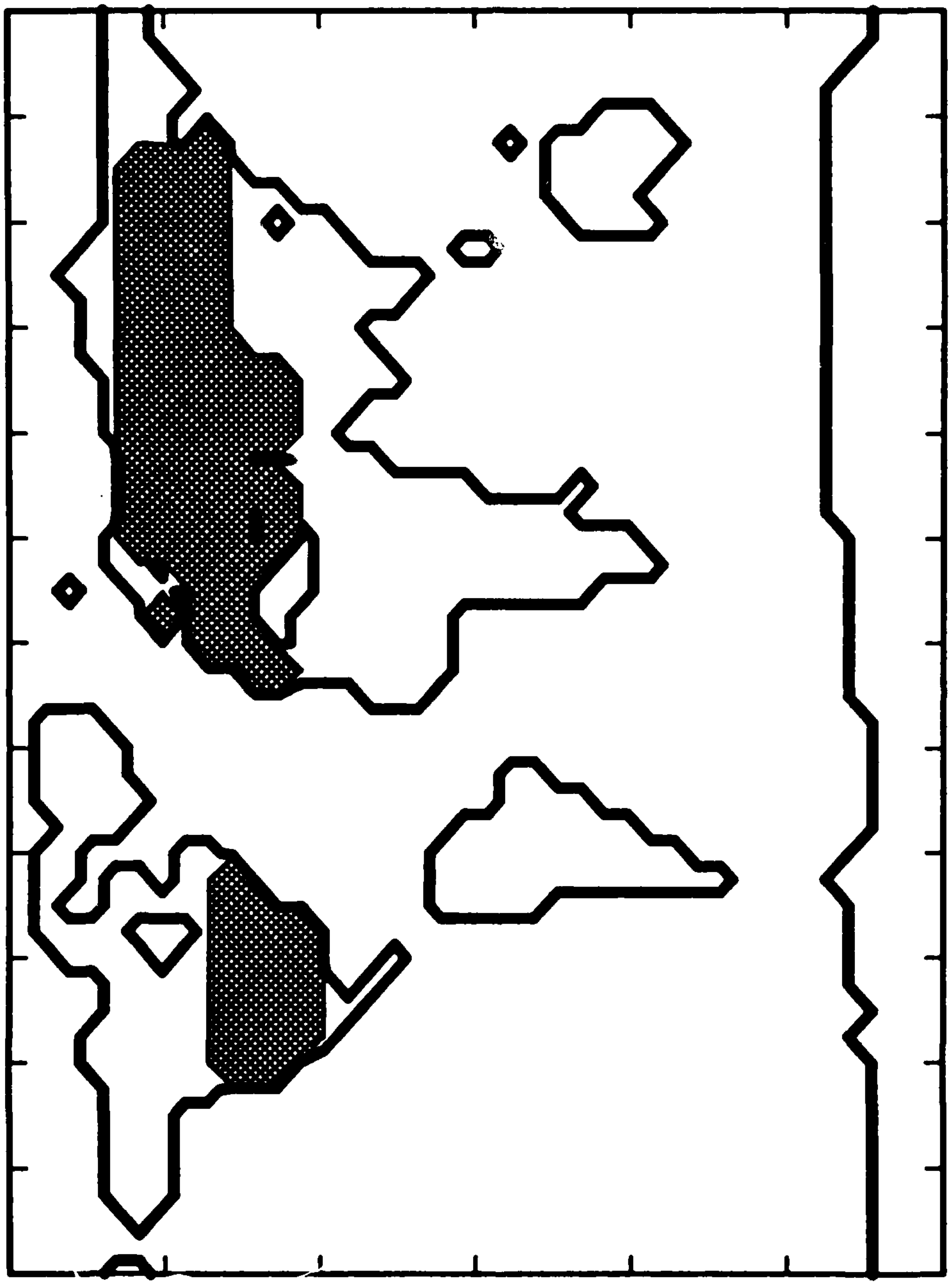
Large-Scale Movement of Smoke and Dust

- Use of separate tracer transport models
- Development of simple, yet accurate positive-definite tracer methods for use inside 3-D models

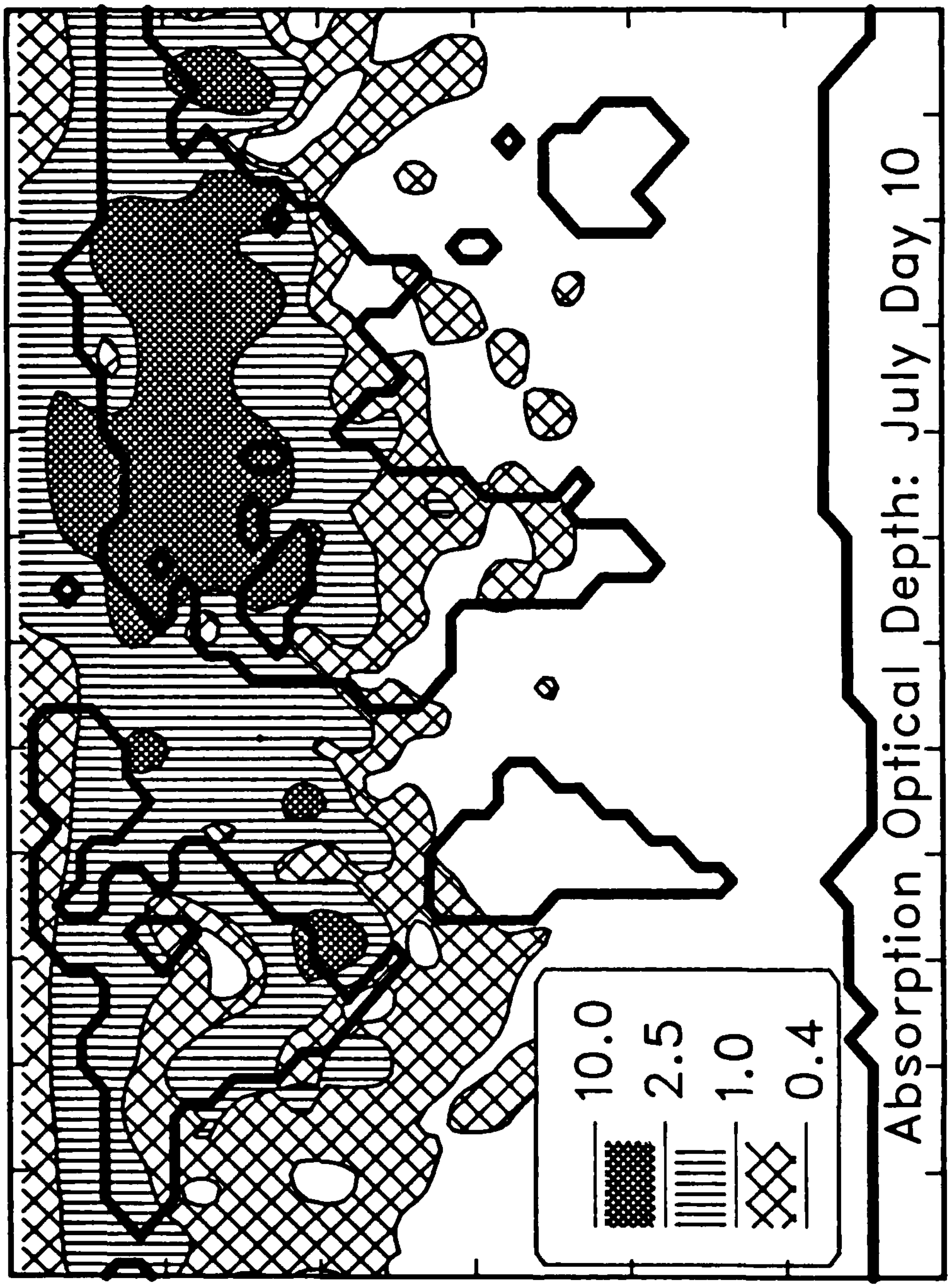
Smoke and Dust Removal

- Improved parameterization of convective precipitation
- Smoke and dust scavenging by precipitation
- Smoke and dust effects on cloud microphysics
- Smoke particle coagulation in dense plumes
- Time evolution of chemical composition of smoke
- Dry deposition at the surface

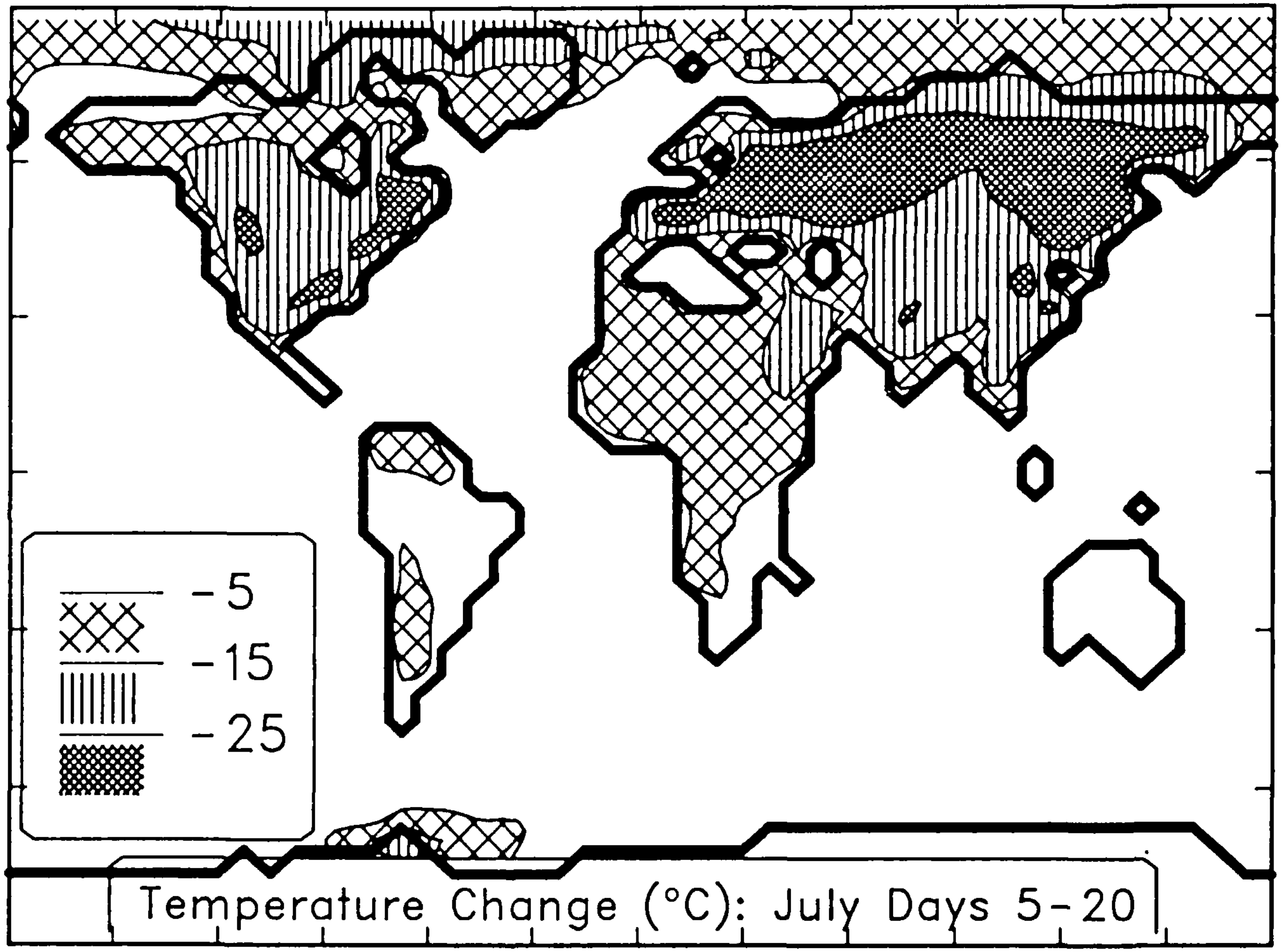
NCAR (1984)



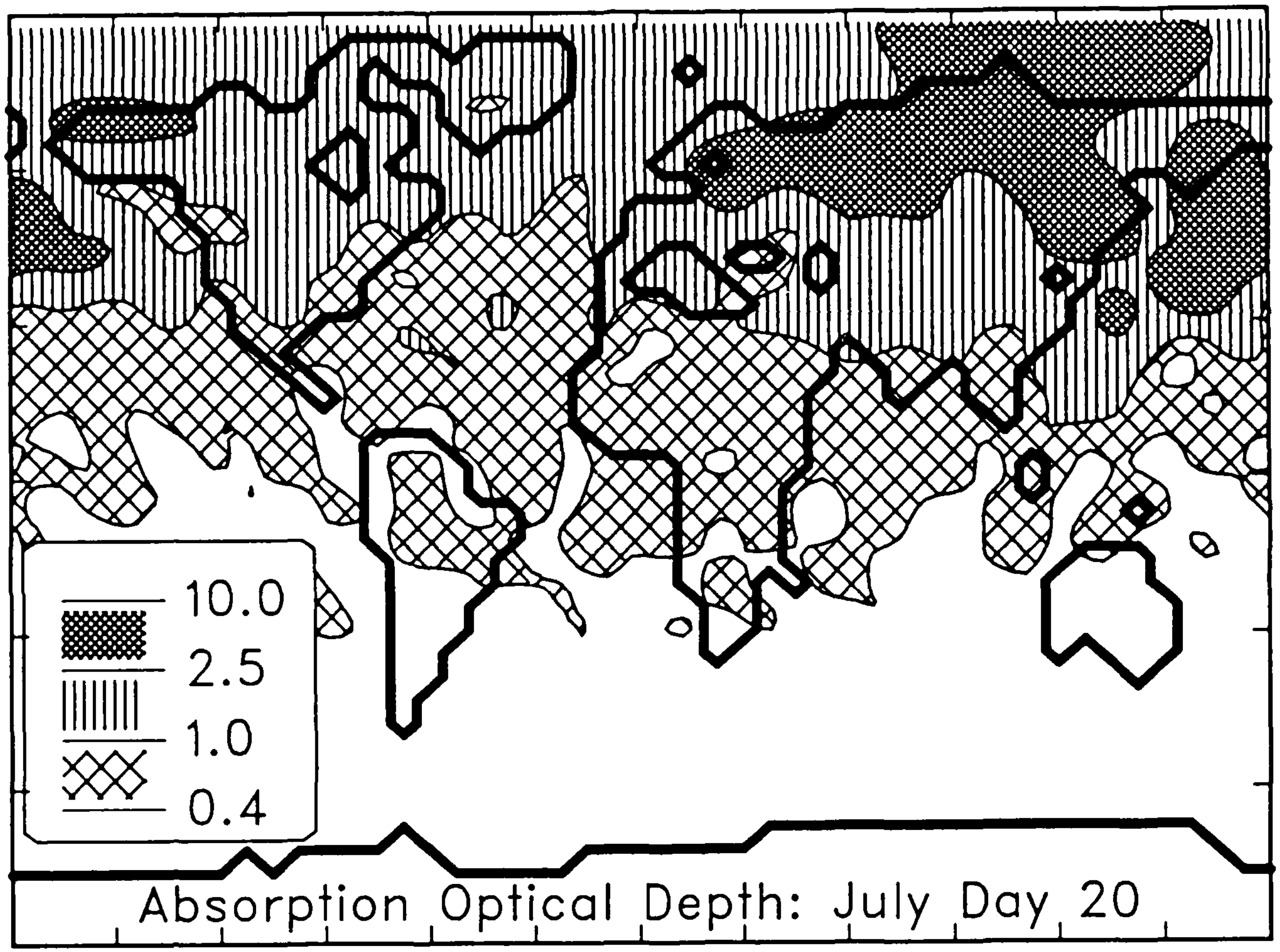
Thompson (1985)



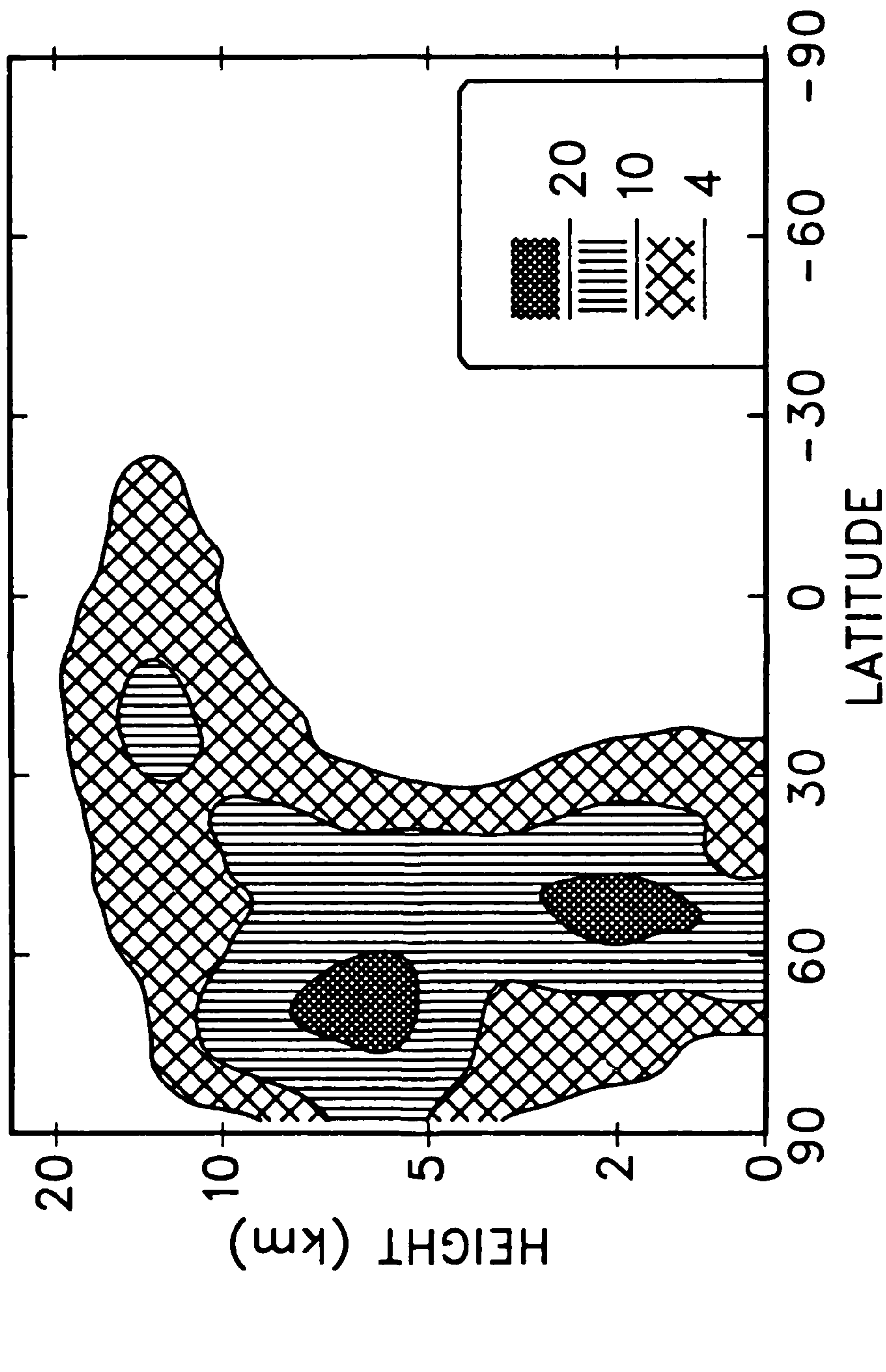
Thompson (1985)



Thompson (1985)

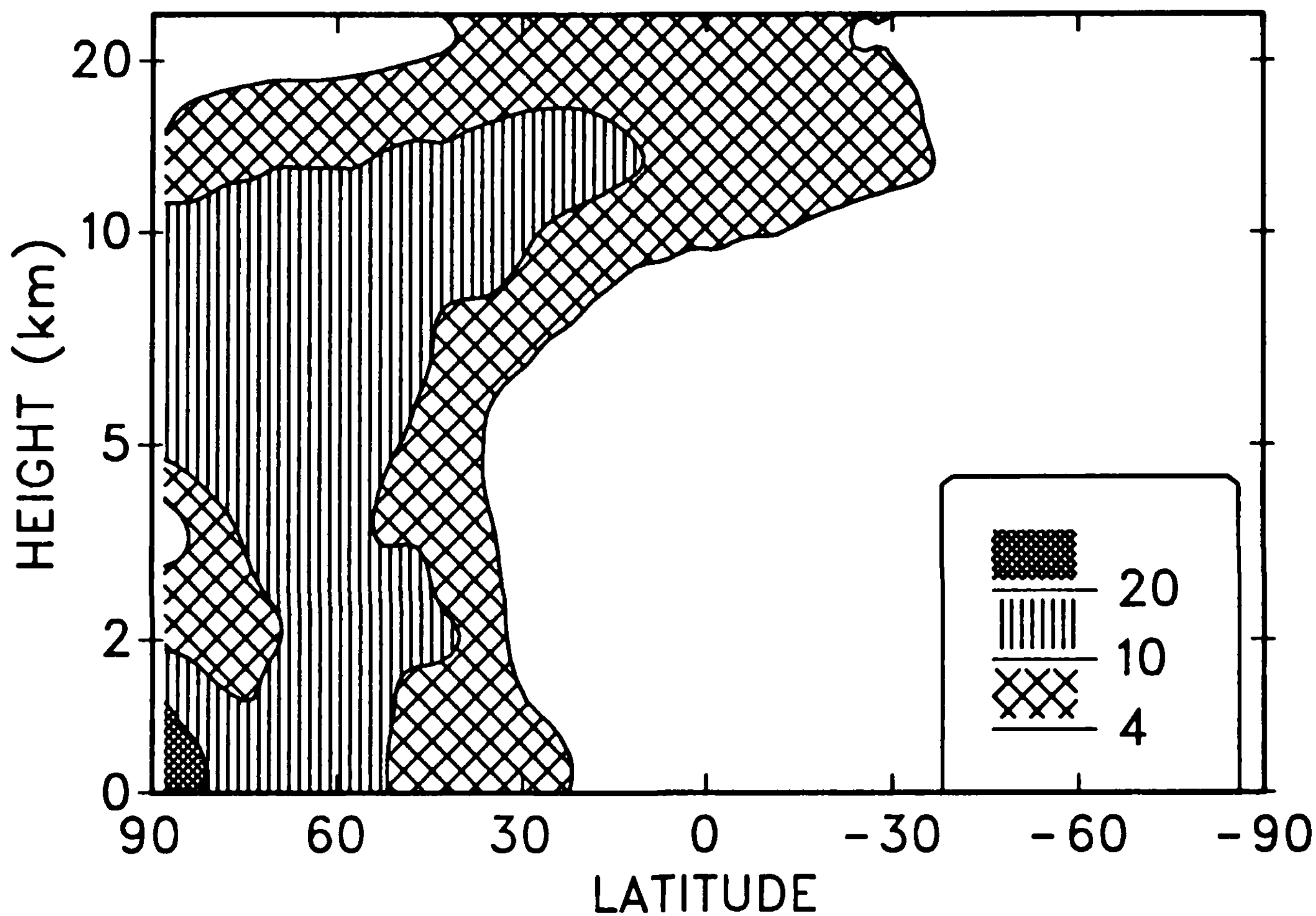


Thompson (1985)



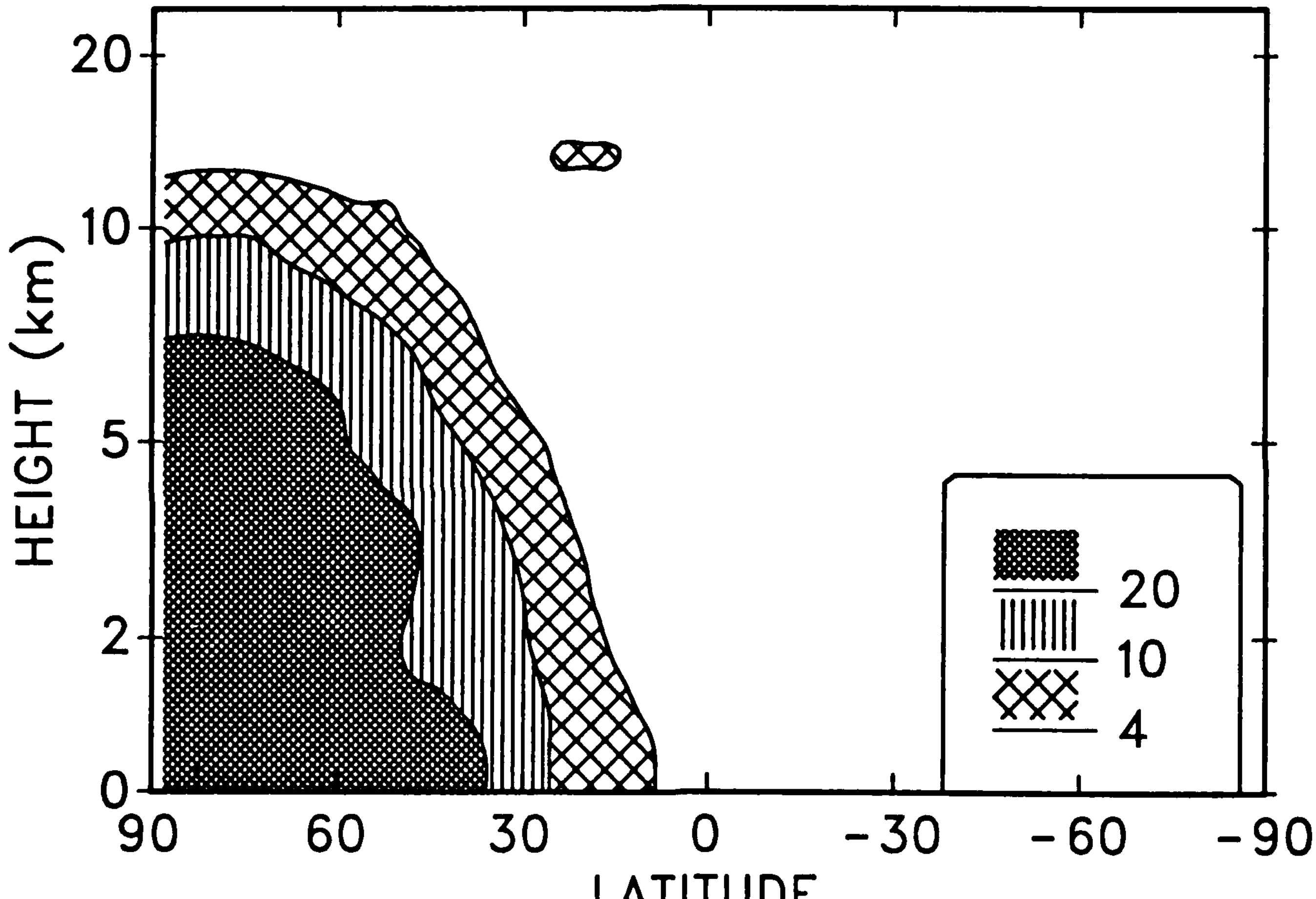
Smoke Mixing Ratio ($\times 10^{-8}$), July, Day 10

Thompson (1985)



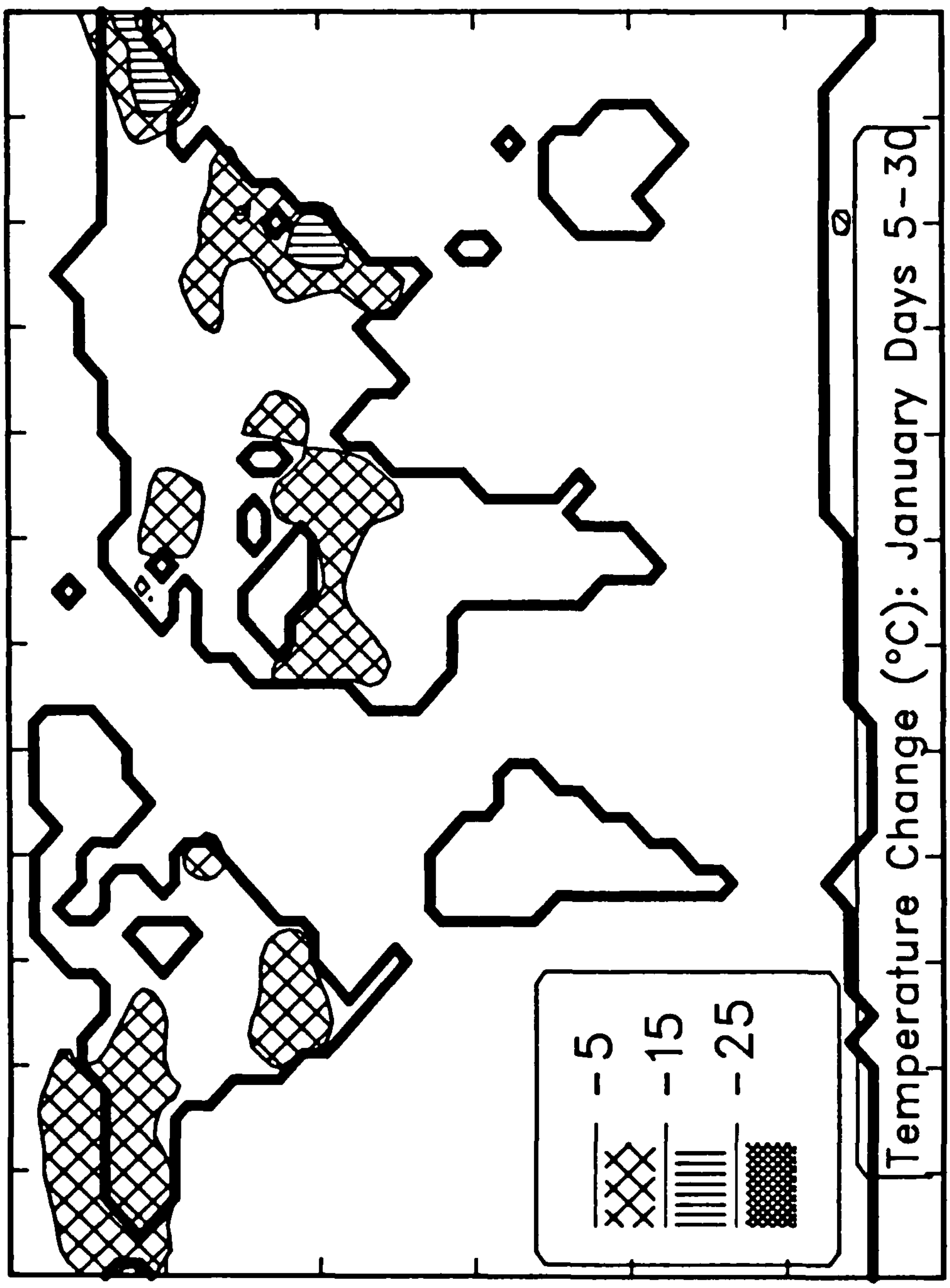
Smoke Mixing Ratio ($\times 10^{-8}$), July, Day 20

Thompson (1985)

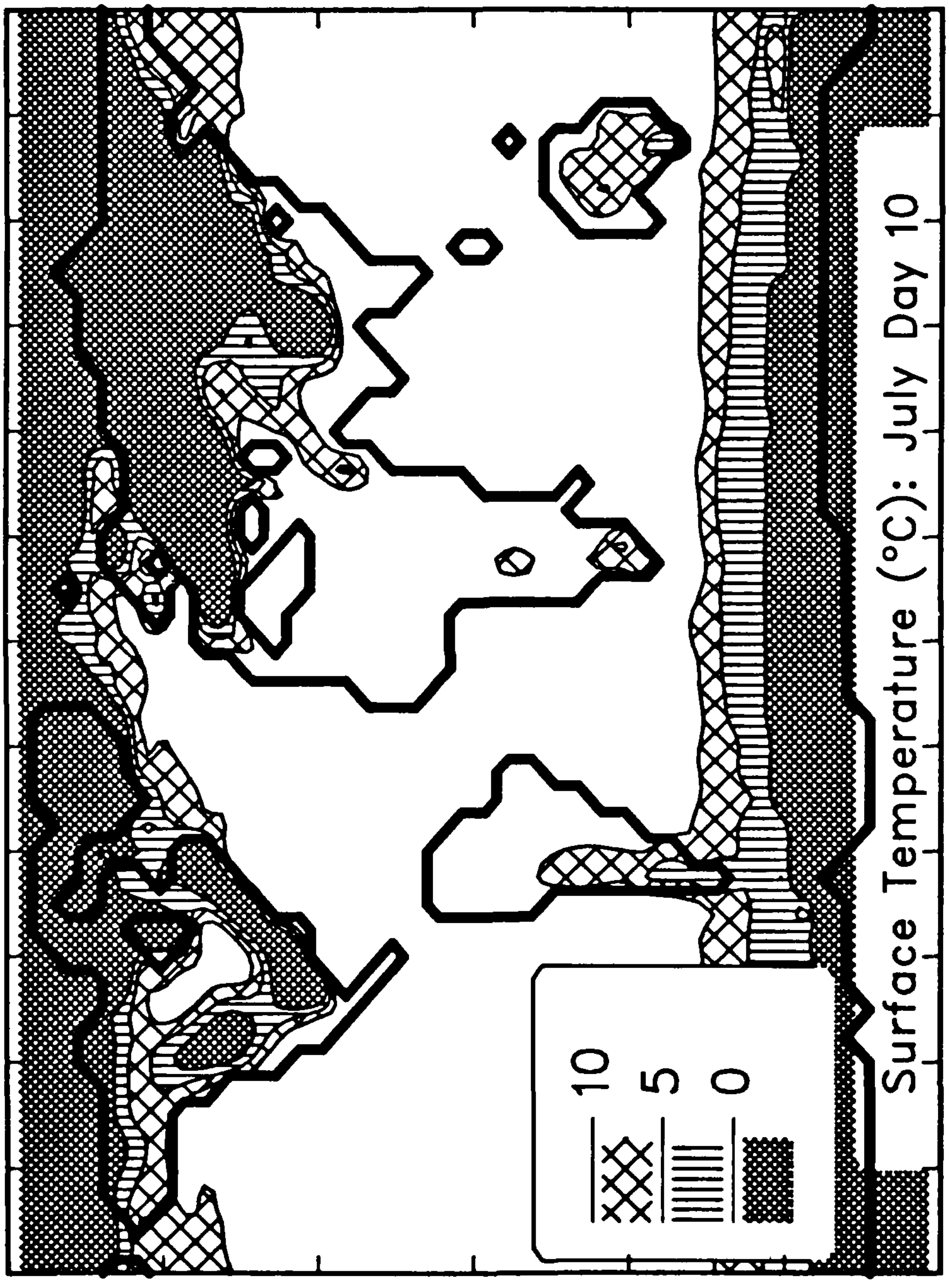


Smoke Mixing Ratio ($\times 10^{-8}$), January, Day 30

Thompson (1985)



Thompson (1985)



Thompson (1985)

NCAR Global Model

Model Type:

- Global atmospheric general circulation model.

Resolution:

- 4.5° latitude by 7.5° longitude grid.
- 9 layers in the vertical.

Physical Processes:

- Smoke transport. (Spectral advection)
- Smoke solar absorption and scattering. (Fixed diurnal mean Sun)
- Smoke infrared absorption.
- No smoke removal.

NCAR (1985)

Smoke Scenarios

Smoke Mass:
- 180 Tg (National Research Council, 1985)
- 60 Tg

Geographic Area:
- Initially over portions of NATO and Warsaw Pact.

Height:
- Initially 0 – 7 km.

Duration:
- Smoke injection at a constant rate over 2 days. No removal.

Season:
- Northern Hemisphere summer (July)
- Northern Hemisphere winter (January)

NCAR (1985)

Radiative Transfer Enhancements

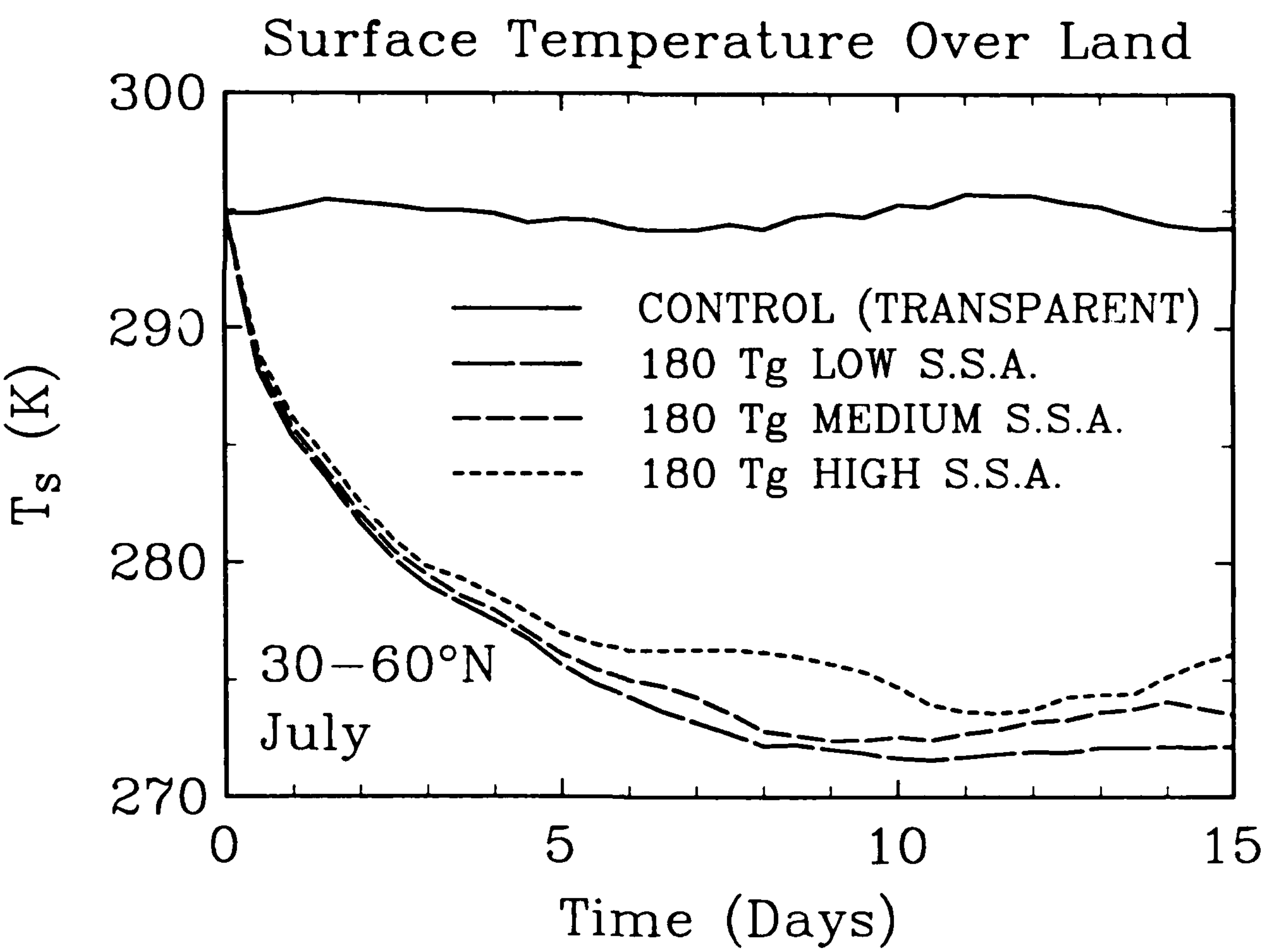
Smoke Scattering of Solar Radiation
(With V. Ramaswamy)

- δ–Eddington for Visible and Near–IR
- Fixed smoke optical properties
- Visible specific extinction: 5.5 m^2g^{-1}
- Visible single scattering albedo:
  Low=0.45, Medium=0.60, High=0.75

Smoke Thermal Infrared Opacity
(Model enhancements by Curt Covey)

- Gray absorber approximation
- Specific absorption (nominal): 0.5 m^2g^{-1}

NCAR (1985)


Surface Temperature Over Land
300
290
280
270
T_s (K)
CONTROL (TRANSPARENT)
180 Tg LOW S.S.A.
180 Tg MEDIUM S.S.A.
180 Tg HIGH S.S.A.
30–60°N
July
0
5
10
15
Time (Days)

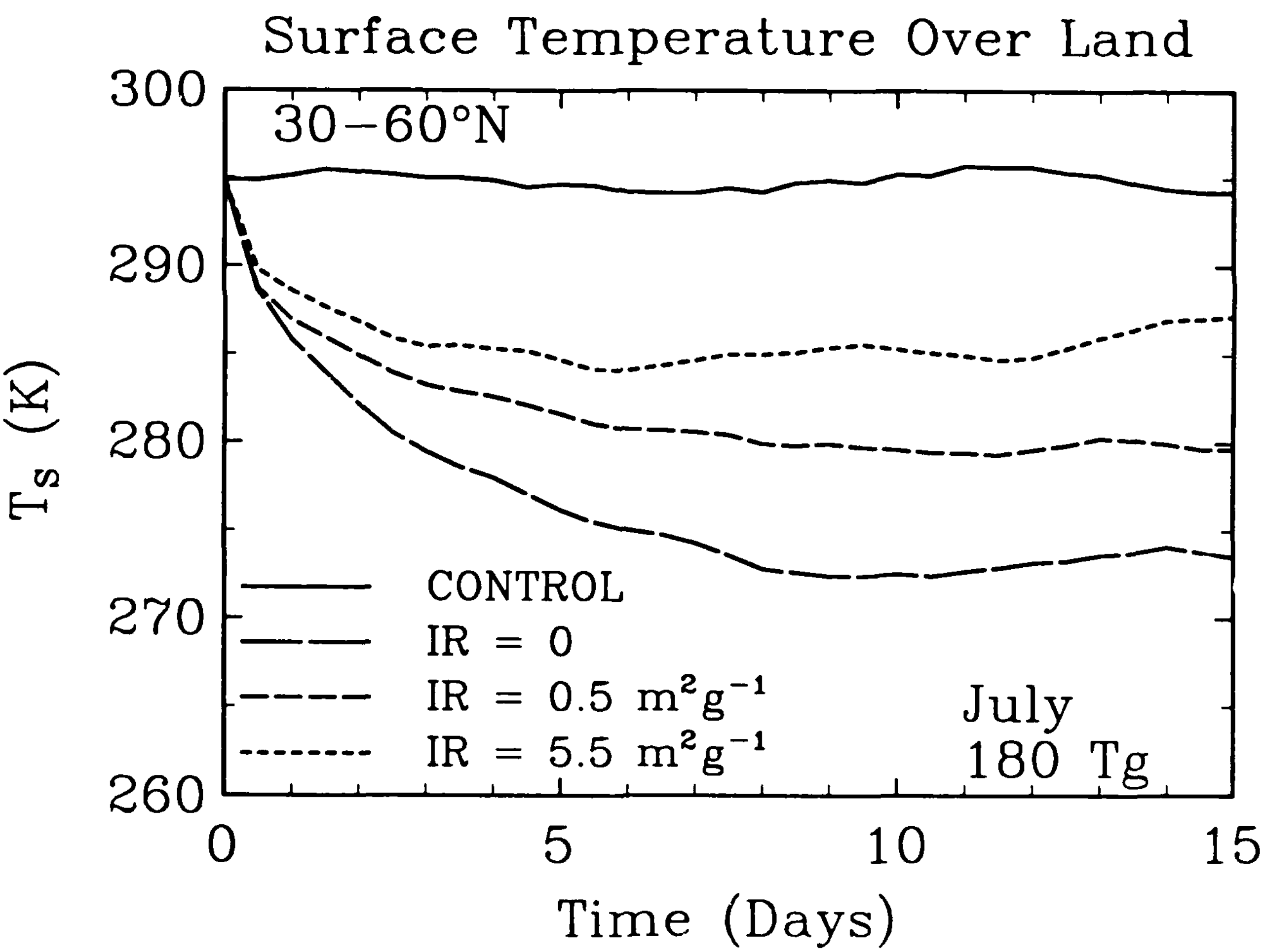
NCAR (1985)

Conclusions From Scattering Sensitivity Tests

For Fixed July Diurnal Mean Sun:

- Plausible range of scattering has little effect on rate of smoke lofting and transport.
- For fixed specific absorption, going from non–scattering to mid–range scattering decreases land surface temperature by about 2°C.
- For fixed specific extinction, the plausible range of scattering changes land surface temperature by ±3°C.

NCAR (1985)



Surface Temperature Over Land
30-60°N
300
290
280
270
260
T_S (K)
0
5
10
15
Time (Days)
CONTROL
IR = 0
IR = 0.5 m^2g^{-1}
IR = 5.5 m^2g^{-1}
July
180 Tg

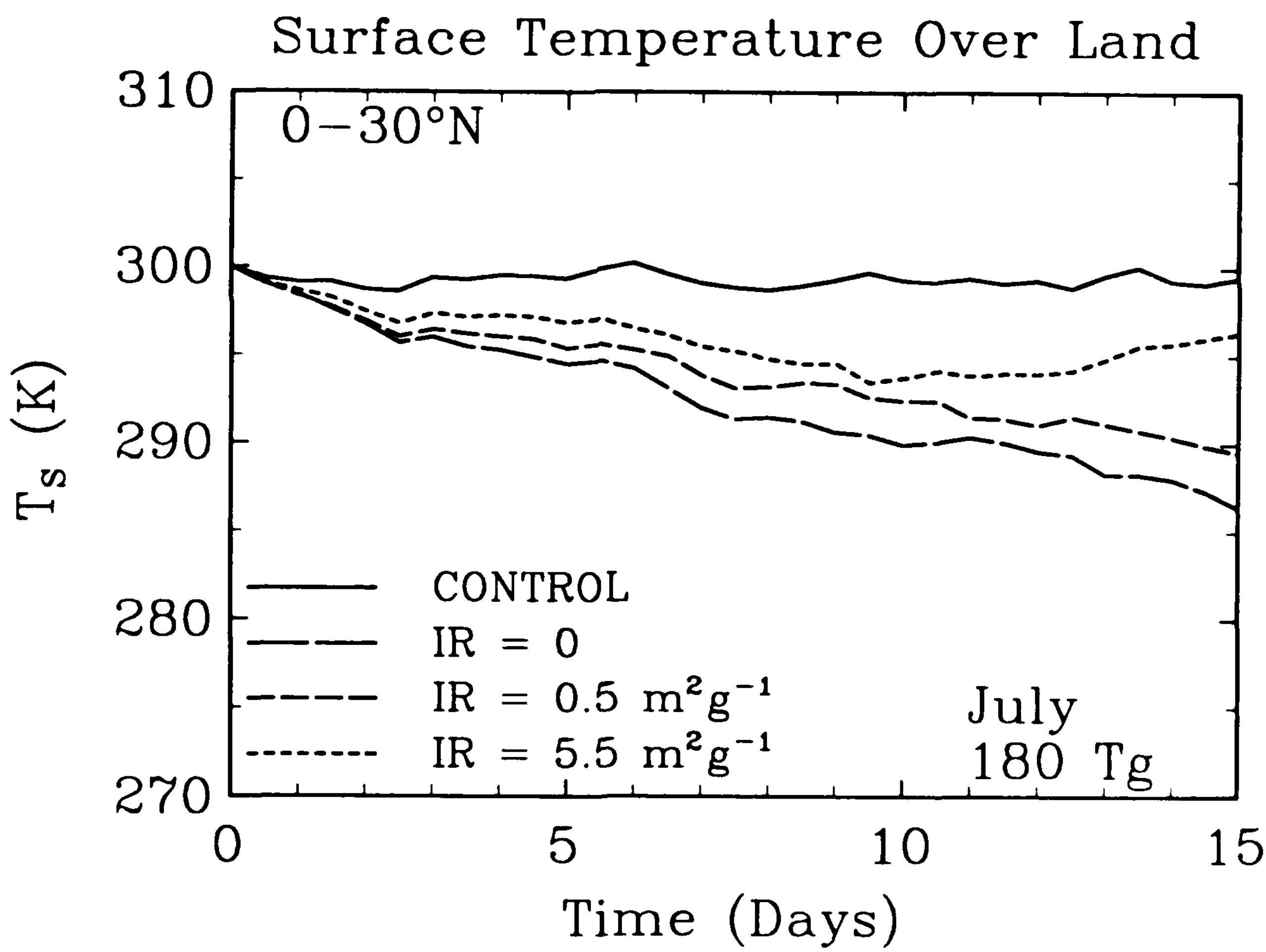
NCAR (1985)

Conclusions From IR Sensitivity Tests

July 180 Tg Cases:
With IR Smoke Opacity Vs. Without

- Nominal smoke IR opacity mitigates land surface temperature drop by roughly 25%.
- VERY large smoke IR opacity mitigates land surface temperature drop by roughly 50%.

NCAR (1985)


Surface Temperature Over Land
0-30°N
310
300
290
280
270
Ts (K)
0
5
10
15
Time (Days)
CONTROL
IR = 0
IR = 0.5 m²g⁻¹
IR = 5.5 m²g⁻¹
July
180 Tg

NCAR (1985)

Infrared Effects of Smoke:
Parameterizations for Dynamical Models

Curt Covey
RSMAS/MPO, U. of Miami

J. T. Kiehl, Starley L. Thompson
NCAR

DNA Global Effects Program Technical Meeting
NASA Ames Research Center, 25-27 February 1986

<u>Conclusions for NAS "baseline" smoke amounts and optical properties:</u>

1. In GCM calculations, IR greenhouse effect moderates "nuclear winter" but comes nowhere near reversing it.

2. "Gray smoke" approximation provides a slight overestimate of the magnitude of the IR effect, compared with frequency-dependent smoke IR absorption and emission.

3. IR effects may be more important for mesoscale modeling of initial smoke injection. The parameterization discussed here could be used for such models.

BROAD-BAND EMISSIVITY / ABSORPTIVITY FORMULATION

(Ramaswamy and Kiehl, 1985)

<u>Required input to IR calculations:</u>

$$\varepsilon = (\sigma T^4)^{-1} \int (1 - T_\omega)\, B_\omega \, d\omega$$

$$\alpha = (4\sigma T^3)^{-1} \int (1 - T_\omega)\, (dB_\omega/dT)\, d\omega$$

where T = temperature
ω = frequency
B_ω = blackbody monochromatic irradiance
T_ω = monochromatic transmissivity
$= T_{H2O} T_{CO2} T_{O3} T_a$
T_x = monochromatic transmissivity of species x
("a" denotes smoke and dust aerosol)

ε and α can be rewritten in the form

$$\varepsilon = \varepsilon_{H2O} + \varepsilon_{A\text{-}H2O} + \varepsilon_{O3} \overline{T}_a^{(2)} + \varepsilon_{CO2} \overline{T}_a^{(3)} \overline{T}_{H2O}^{(3)}$$

where $\overline{T}_x^{(i)}$ denotes average transmissivity of x in a frequency band,

ε_{H2O}, ε_{CO2}, ε_{O3} are emissivities of single species in the absence of other species, and

$$\varepsilon_{A\text{-}H2O} = (\sigma T^4)^{-1} \int (1 - T_a)\, T_{H2O}\, B_\omega \, d\omega$$

FOUR-BAND PARAMETERIZATION FOR ε_{A-H2O}

$$\varepsilon_{A-H2O} = \sum_{i=1}^{4} (1 - \bar{T}_a^{(i)})\bar{T}_{H2O}^{(i)} p^{(i)}, \text{ where}$$

the four bands are 4-8 μm (i=1)
8-12 μm (i=2)
12-16 μm (i=3)
16-500 μm (i=4)

$\bar{T}_a^{(i)}$ = transmissivity of smoke and dust aerosol
$= \exp [-(c_s^{(i)} u_s + c_d^{(i)} u_d)]$

$\bar{T}_{H2O}^{(i)}$ = transmissivity of water vapor
$= A_i \exp (-B_i u_{H2O})$

$p^{(i)}$ = Planck weighting function
$= C1^{(i)} - C2^{(i)}(300 - T)$

u_s = smoke column density [g cm^{-2}]

u_d = dust column density [g cm^{-2}]

$c_s^{(i)}$ = smoke IR absorption coefficient [cm^2 g^{-1}]

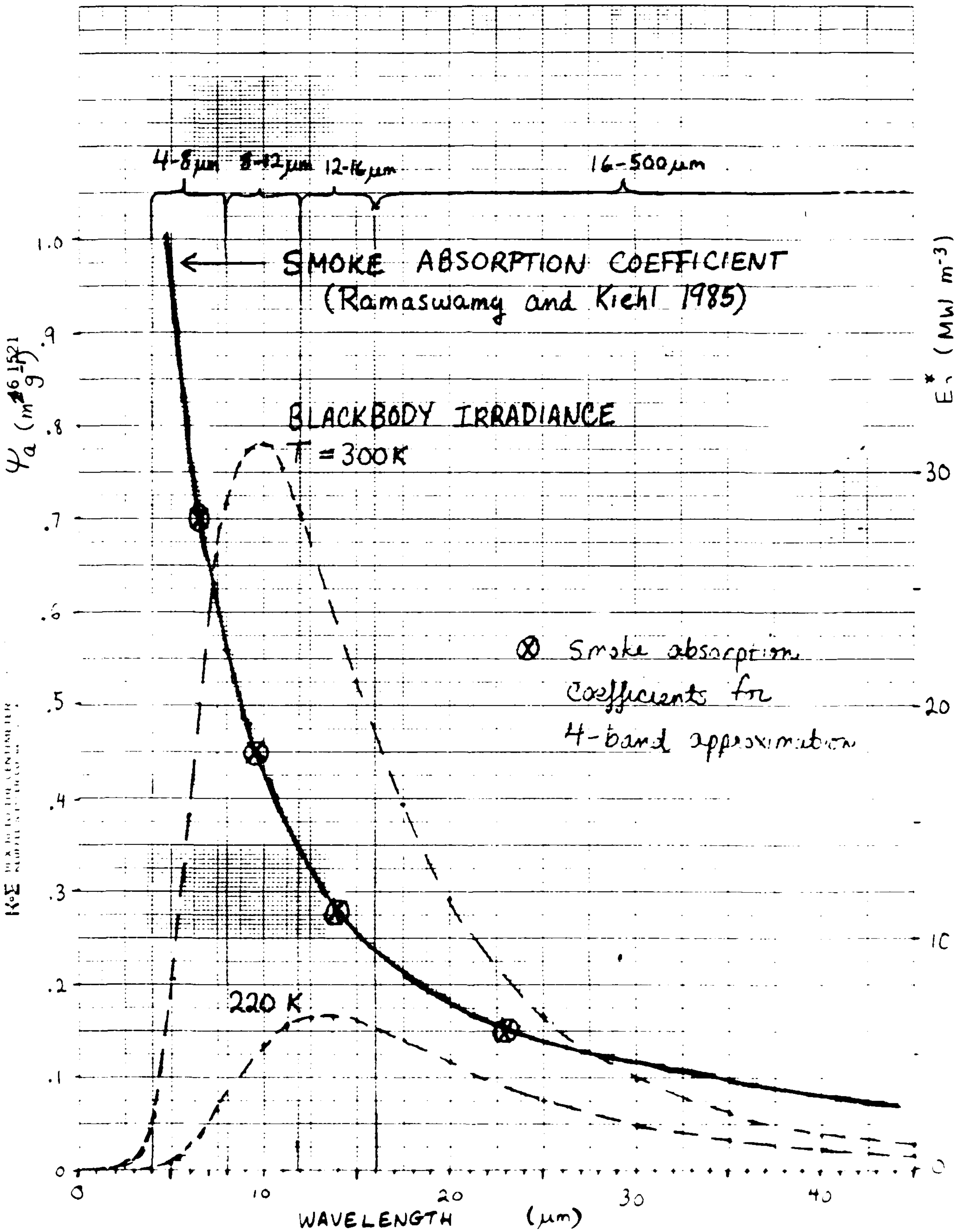
$c_d^{(i)}$ = dust IR absorption coefficient [cm^2 g^{-1}]

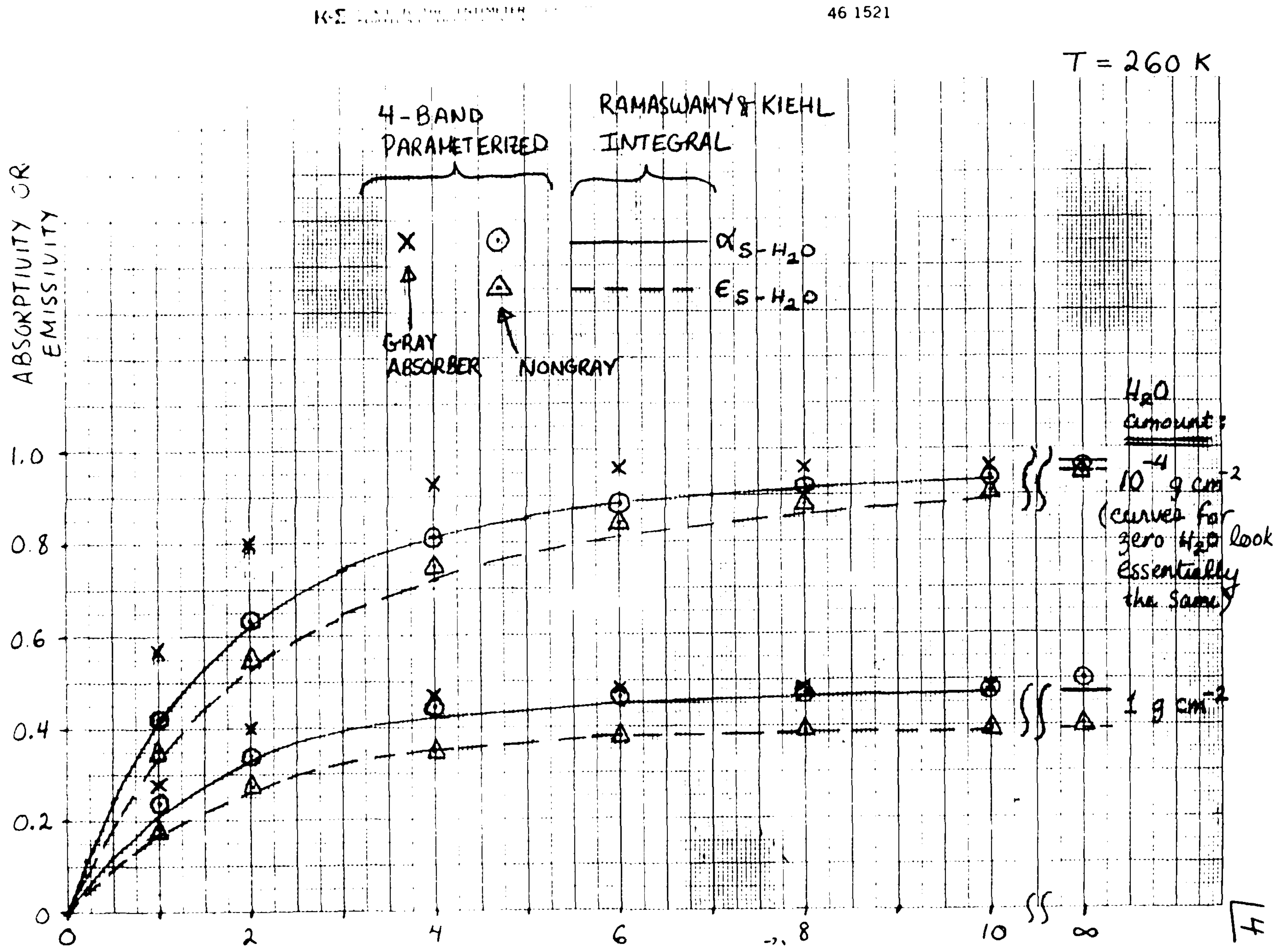
u_{H2O} = pressure-weighted water vapor column density [g cm^{-2}]

T = temperature [K]

Note:

Parameters for smoke and dust IR absorption are obtained from Ramaswamy and Kiehl (1985). Parameters for water vapor IR absorption and Planck weights are chosen to fit the narrow band computations of Rodgers and Walshaw (1966).


4-8 μm
8-12 μm
12-16 μm
16-500 μm
SMOKE ABSORPTION COEFFICIENT
(Ramaswamy and Kiehl 1985)
BLACKBODY IRRADIANCE
T = 300 K
220 K
⊗ Smoke absorption coefficients for 4-band approximation
WAVELENGTH (μm)
0
10
20
30
40
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
30
20
10
0



K-E
46 1521
T = 260 K
4-BAND PARAMETERIZED
RAMASWAMY & KIEHL INTEGRAL
α_{S-H_2O}
ϵ_{S-H_2O}
GRAY ABSORBER
NONGRAY
ABSORPTIVITY OR EMISSIVITY
H_2O amount:
10^{-4} g cm^{-2}
(curves for zero H_2O look essentially the same)
1 g cm^{-2}
0
0.2
0.4
0.6
0.8
1.0
0
2
4
6
8
10
∞
4

Temperature dependence
($u_S = 2\ g\ m^{-2}$; $u_d = 0$; $u_{H2O} = 10^{-4}\ g\ cm^{-2}$)

ϵ_{A-H2O}

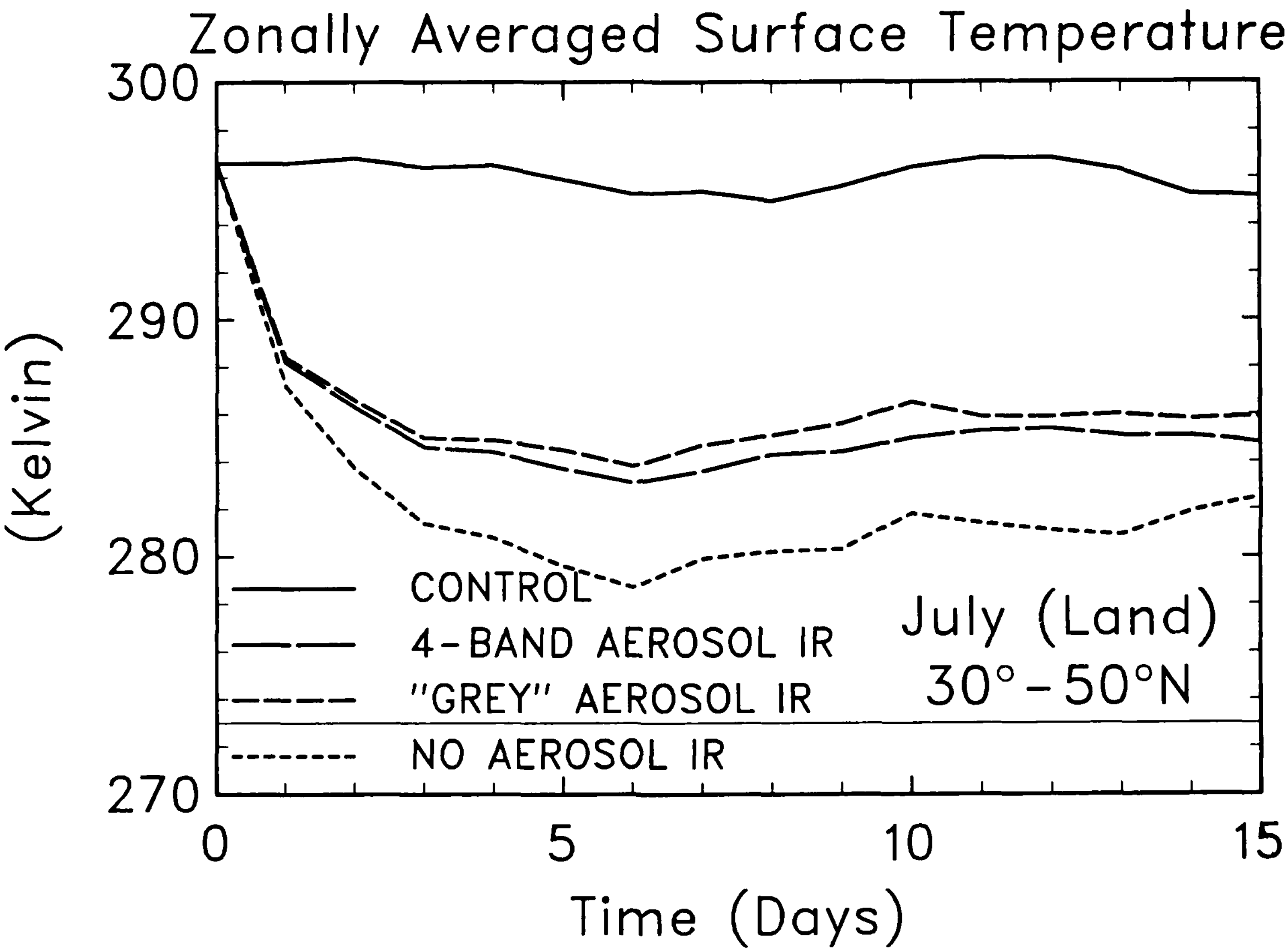
	4-band	Integral
T = 180 K	0.4459	0.3879
340 K	0.6477	0.6150

α_{A-H2O}

	4-band	Integral
180 K	0.5031	0.4803
340 K	0.7571	0.6808

Conclusion: 4-band approx follows T-dependence of Ram + Kiehl to within 15% over an extreme T range.

BUT: The "Integral" formulation does <u>not</u> take into account the T-dependence of H2O absorption (for consistency with CCM). T-dependence comes only from Planck fcn.



Zonally Averaged Surface Temperature
300
290
280
270
(Kelvin)
0
5
10
15
Time (Days)
CONTROL
4-BAND AEROSOL IR
"GREY" AEROSOL IR
NO AEROSOL IR
July (Land)
30°-50°N

NCAR Global Modeling 1985–1986

Starley L. Thompson

and

Filippo Giorgi

V. Ramaswamy

Curt Covey

NCAR Global Modeling: 1985-86

Radiative Transfer Enhancements for Aerosols

- Solar scattering and IR absorption
- Interactive optical properties

Aerosol Transport and Microphysics

- Multiple tracers
- Scavenging parameterizations

Injection Scenario Sensitivity

NCAR Global Model

Model Type:

- Global atmospheric general circulation model.

Resolution:

- 4.5° latitude by 7.5° longitude grid.
- 9 layers in the vertical.

Physical Processes:

- Multiple aerosol transport. (Spectral advection)
- Aerosol solar absorption and scattering. (Fixed diurnal mean Sun)
- Aerosol infrared absorption.
- Aerosol scavenging.

Transport and Microphysics Enhancements

Three Aerosol Tracer Fields

- Smoke mass concentration
- Smoke number concentration
- Dust mass concentration

Microphysics

- Wet removal (in-cloud)
- Sedimentation
- Dry deposition
- Coagulation (intra-specific)

Radiative Transfer Enhancements

Aerosol Scattering of Solar Radiation
(With V. Ramaswamy)

- δ-Eddington for Visible and Near-IR
- Weighted δ-Eddington parameters for multiple aerosol scatterers
- Fixed smoke and dust optical properties
- Smoke optical properties parameterized by *particle radii. (Fits to Mie calculations)*

Aerosol Thermal Infrared Opacity
(Model enhancements by Curt Covey)

- Gray absorber approximation
- 4-band approximation:
  4-8, 8-12, 12-16, 16-500 μm

Aerosol Optical Properties: Solar

Smoke

- "Light" $m=1.5-0.05i$ (ω_o vis ~ 0.75)
- "Medium" $m=1.5-0.10i$ (ω_o vis ~ 0.60)
- "Dark" $m=1.5-0.45i$ (ω_o vis ~ 0.45)
- Fixed $r_g=0.2\mu m$, OR Interactive radii

Dust

- "Glassy" melt-derived basaltic
  ($\lambda=0.51\mu m$, $m=1.53-0.001i$)
  ($\lambda=1.55\mu m$, $m=1.53-0.002i$)
- Fixed $r_g=0.10\mu m$ ("Baseline")
  Fixed $r_g=0.25\mu m$ ("Basaltic")

Aerosol Optical Properties: Infrared

Non-scattering

Specified Specific Absorption

Smoke

- "Grey", specific absorption = 0.5 $m^2 g^{-1}$
- Four broad bands

Dust

- "Grey", specific absorption = 0.1 $m^2 g^{-1}$

Smoke Scenarios

Injected Smoke Mass:
- 180 Tg (National Research Council, 1985)
- 60 Tg

Geographic Area of Injection:
- Portions of NATO and Warsaw Pact

Injection Altitudes:
- 0 - 7 km. (Constant mixing ratio)

Duration of Injection:
- Constant rate over 2 days.
  Constant rate over 10 days. (Protracted)

Dust Scenarios

Injected Dust Mass:

- 40 Tg (National Research Council, 1985)
- 88 Tg ("Excursion")

Geographic Area of Injection:

- Portions of NATO and Warsaw Pact

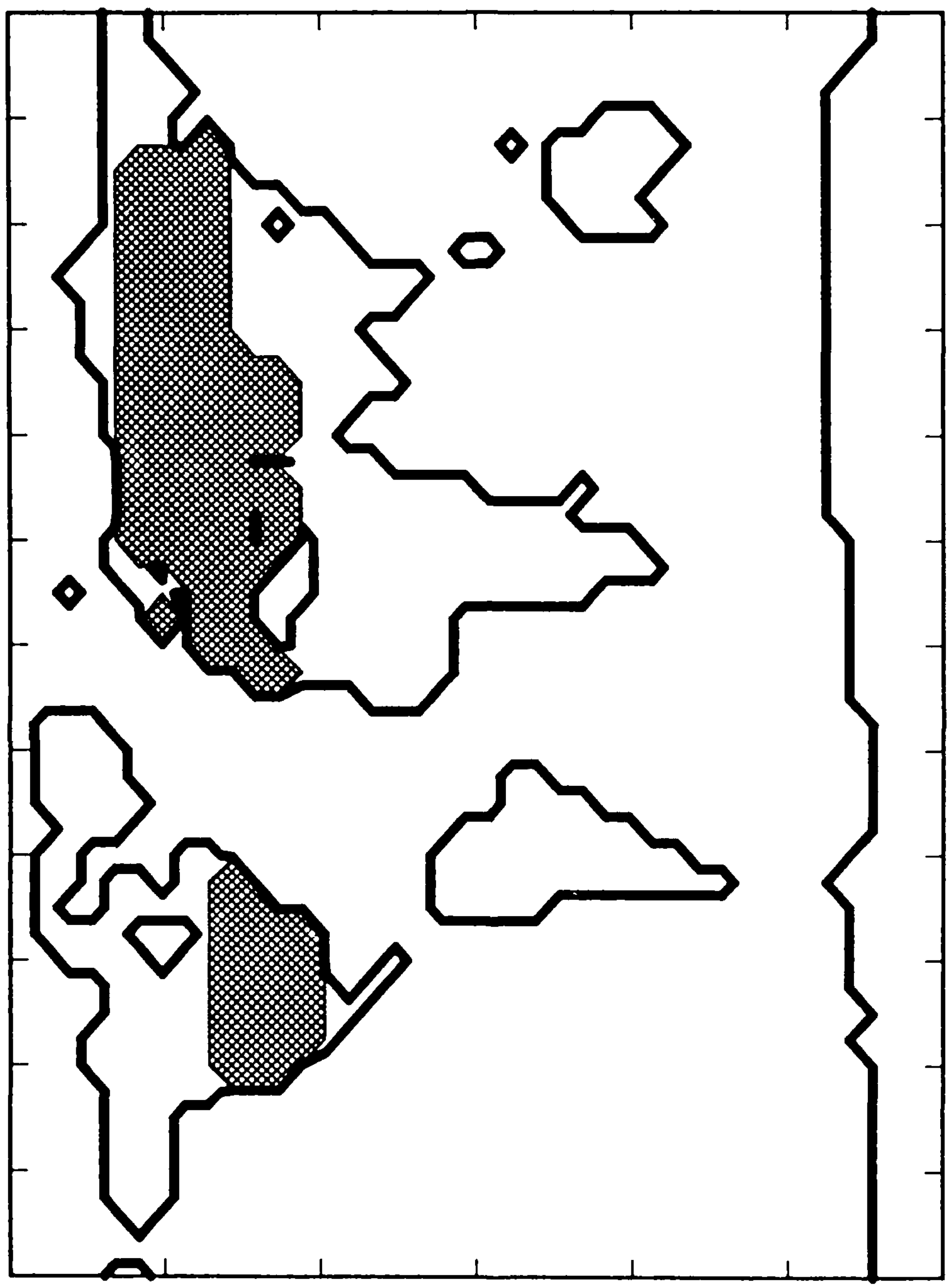
Injection Altitudes:

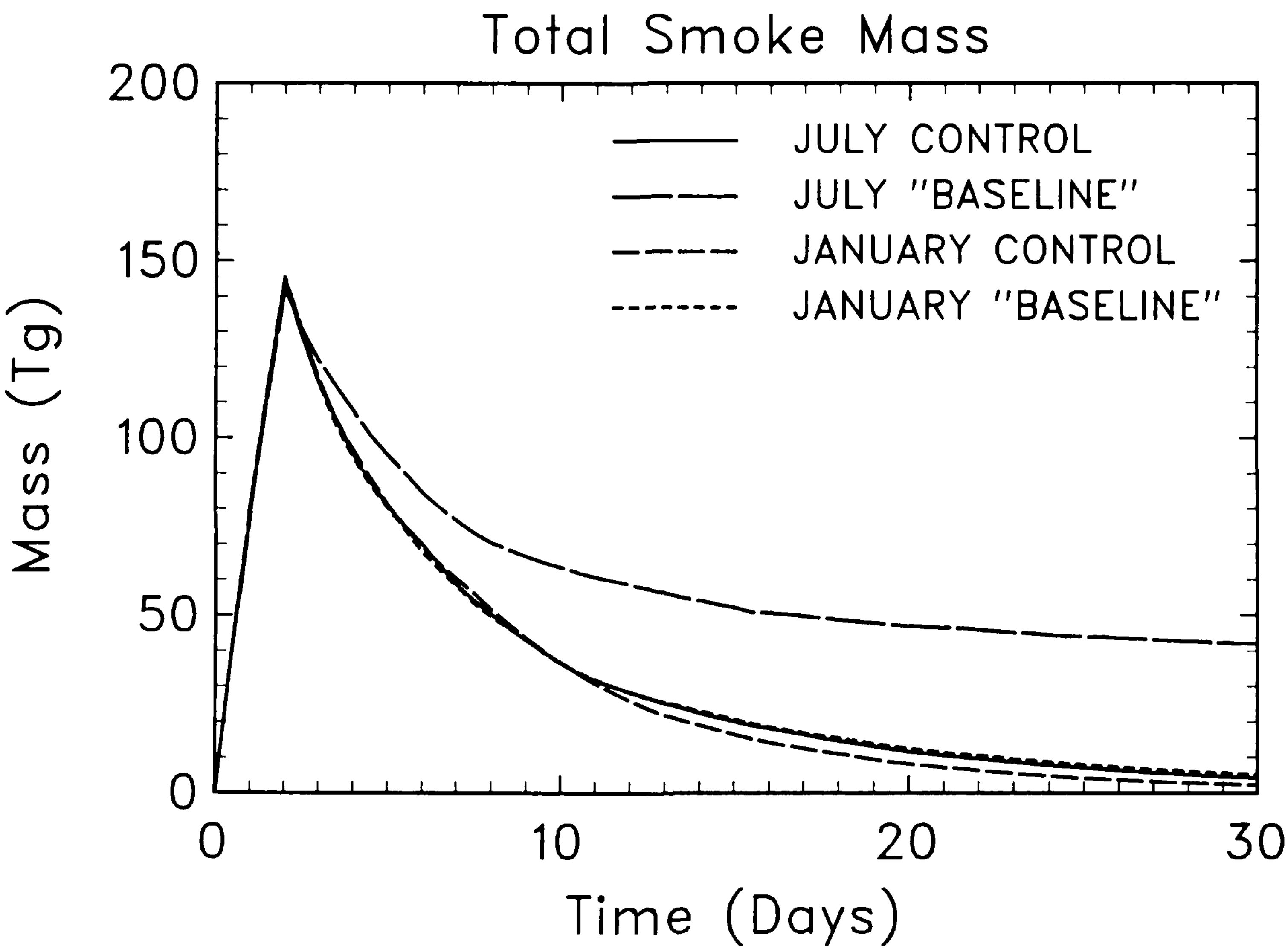
- 7 - 15 km. (Constant mixing ratio)
  10 - 24 km. (Excursion)

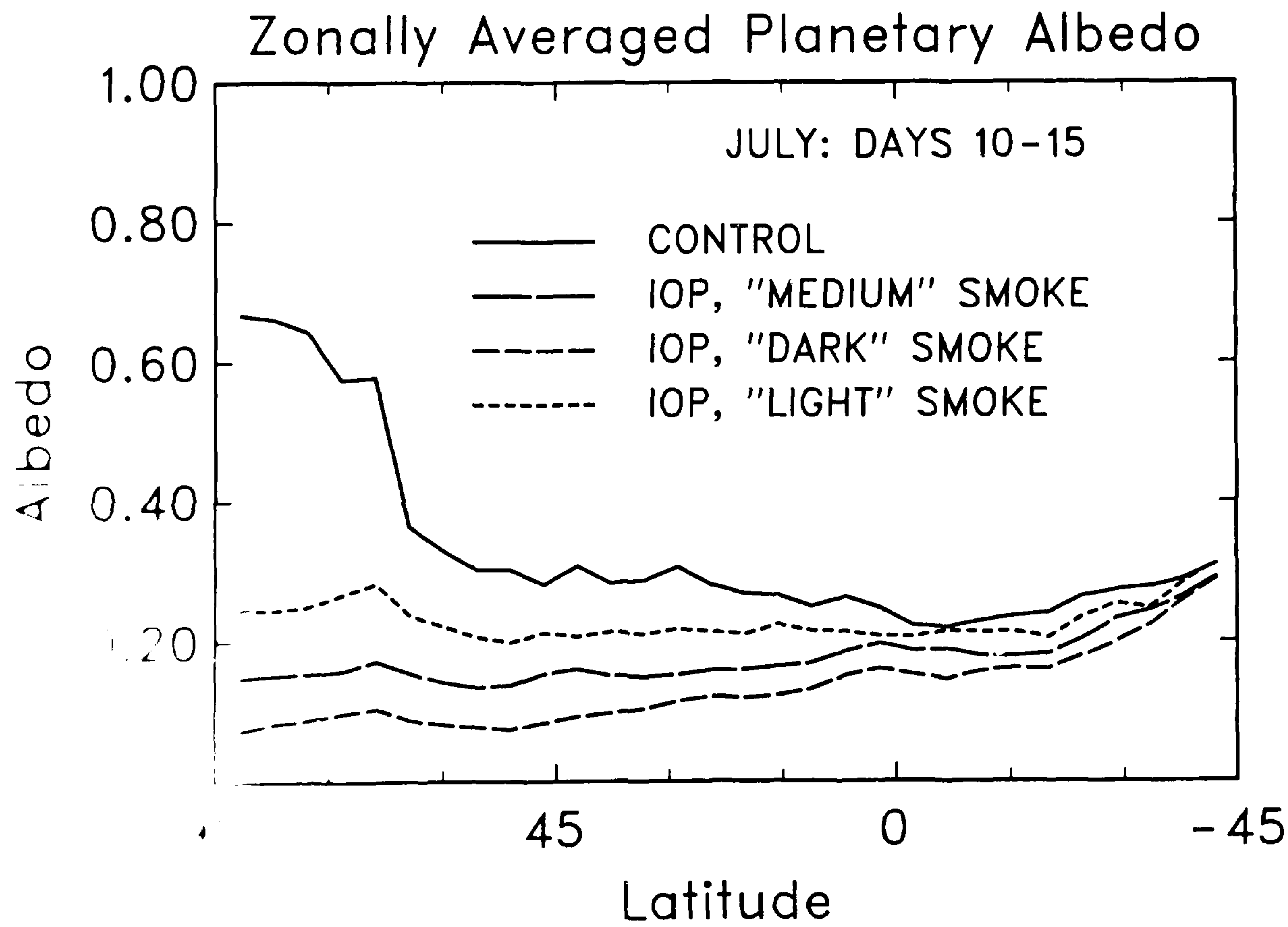
Duration of Injection:

- Constant rate over 1 day.

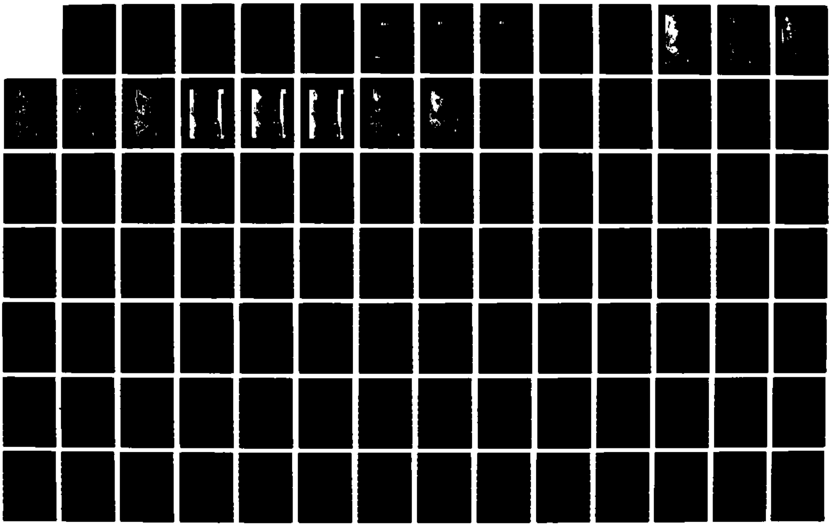
Smoke and Dust Injection Regions

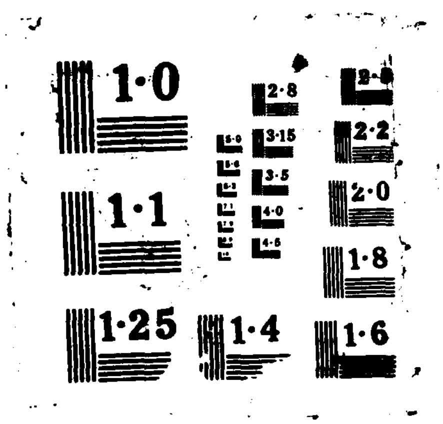



Total Smoke Mass
JULY CONTROL
JULY "BASELINE"
JANUARY CONTROL
JANUARY "BASELINE"
Mass (Tg)
200
150
100
50
0
0
10
20
30
Time (Days)

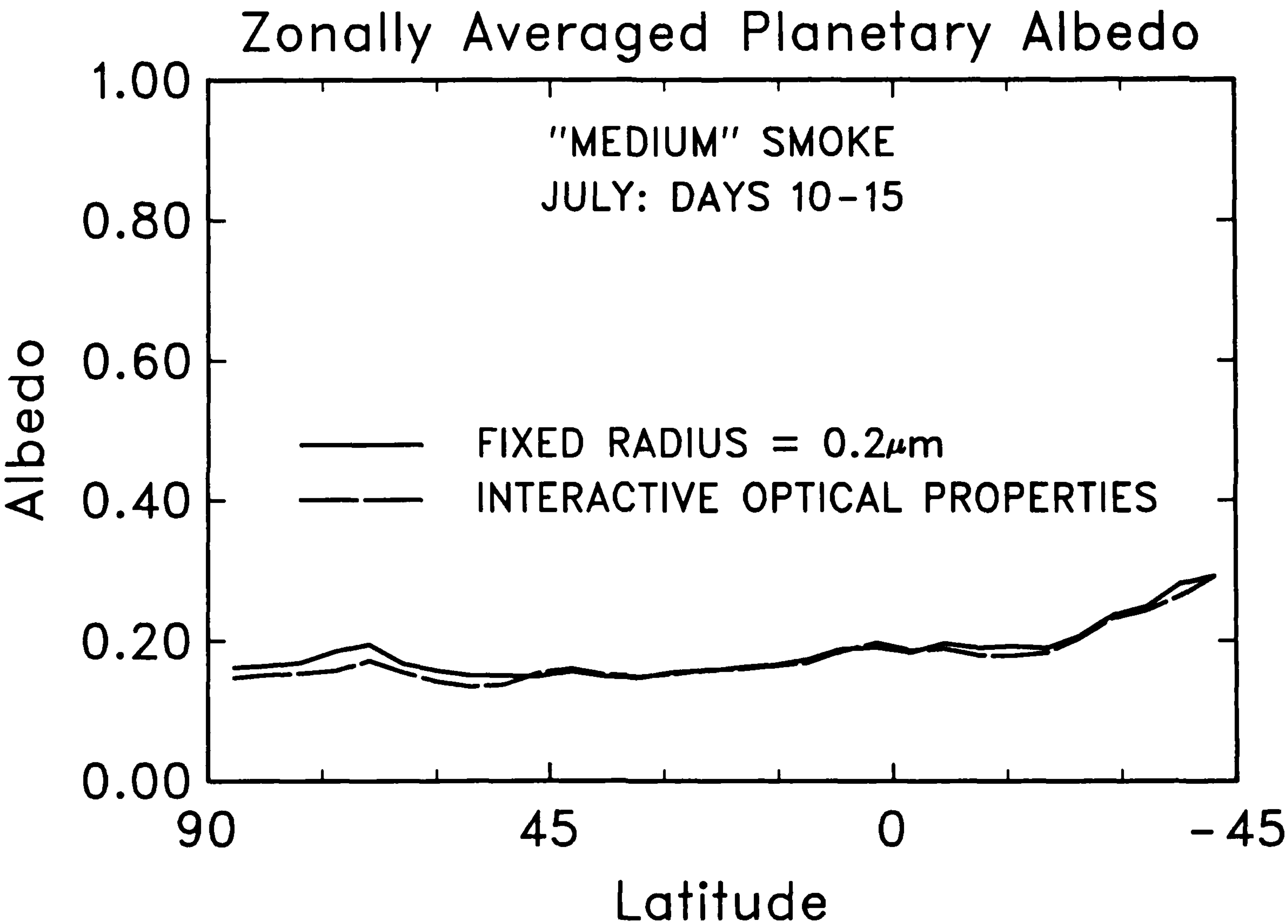

Zonally Averaged Planetary Albedo
JULY: DAYS 10-15
CONTROL
IOP, "MEDIUM" SMOKE
IOP, "DARK" SMOKE
IOP, "LIGHT" SMOKE
Albedo
1.00
0.80
0.60
0.40
45
0
-45
Latitude

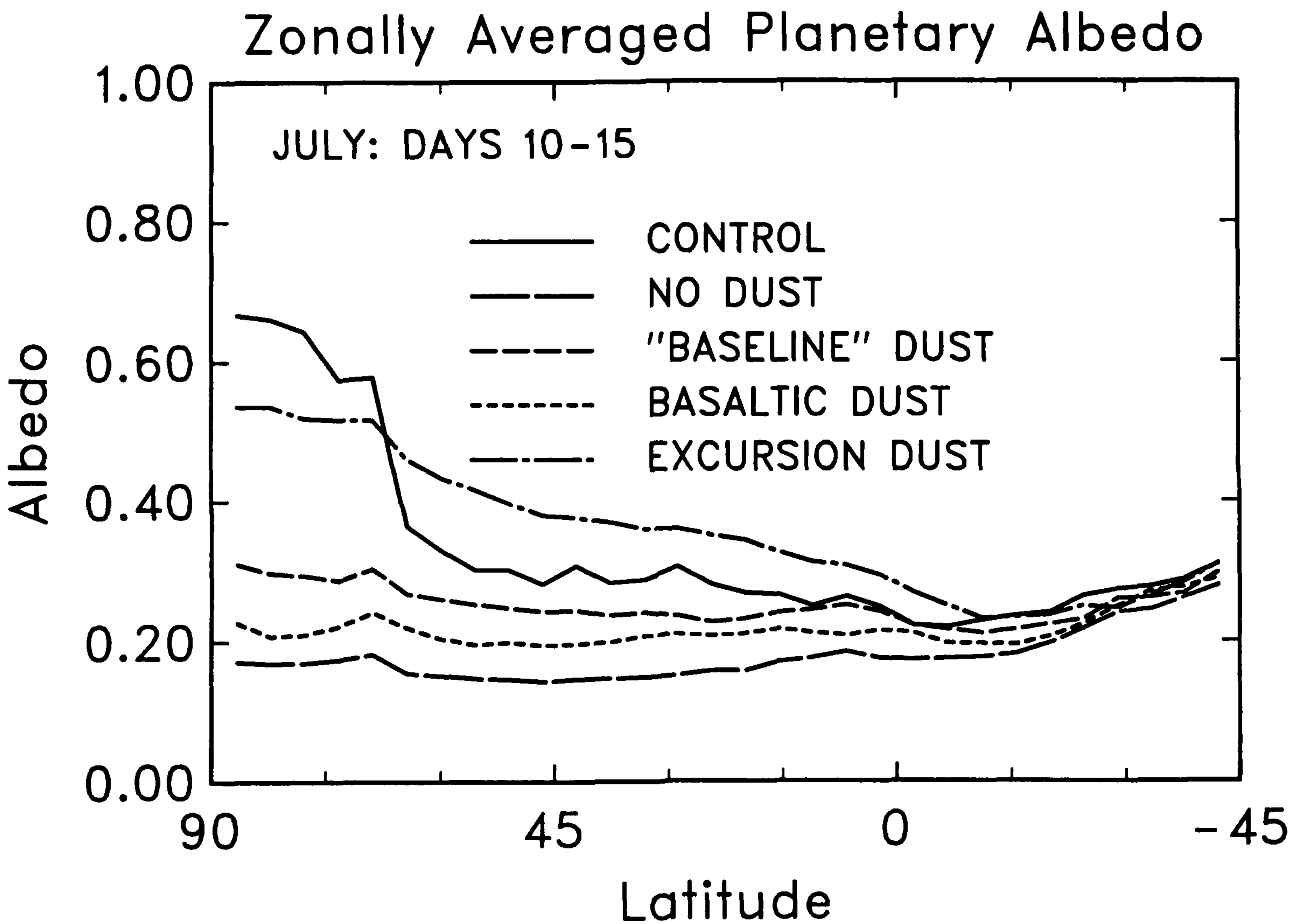
AD-A185 151 TECHNICAL PAPERS PRESENTED AT THE DEFENSE NUCLEAR 2/4
AGENCY GLOBAL EFFECTS R..(U) DOD NUCLEAR INFORMATION
AND ANALYSIS CENTER SANTA BARBARA CA.. 15 MAY 86
UNCLASSIFIED DASIAC-TN-86-29-VOL-3 DNA001-82-C-0274 F/G 15/6.4 NL



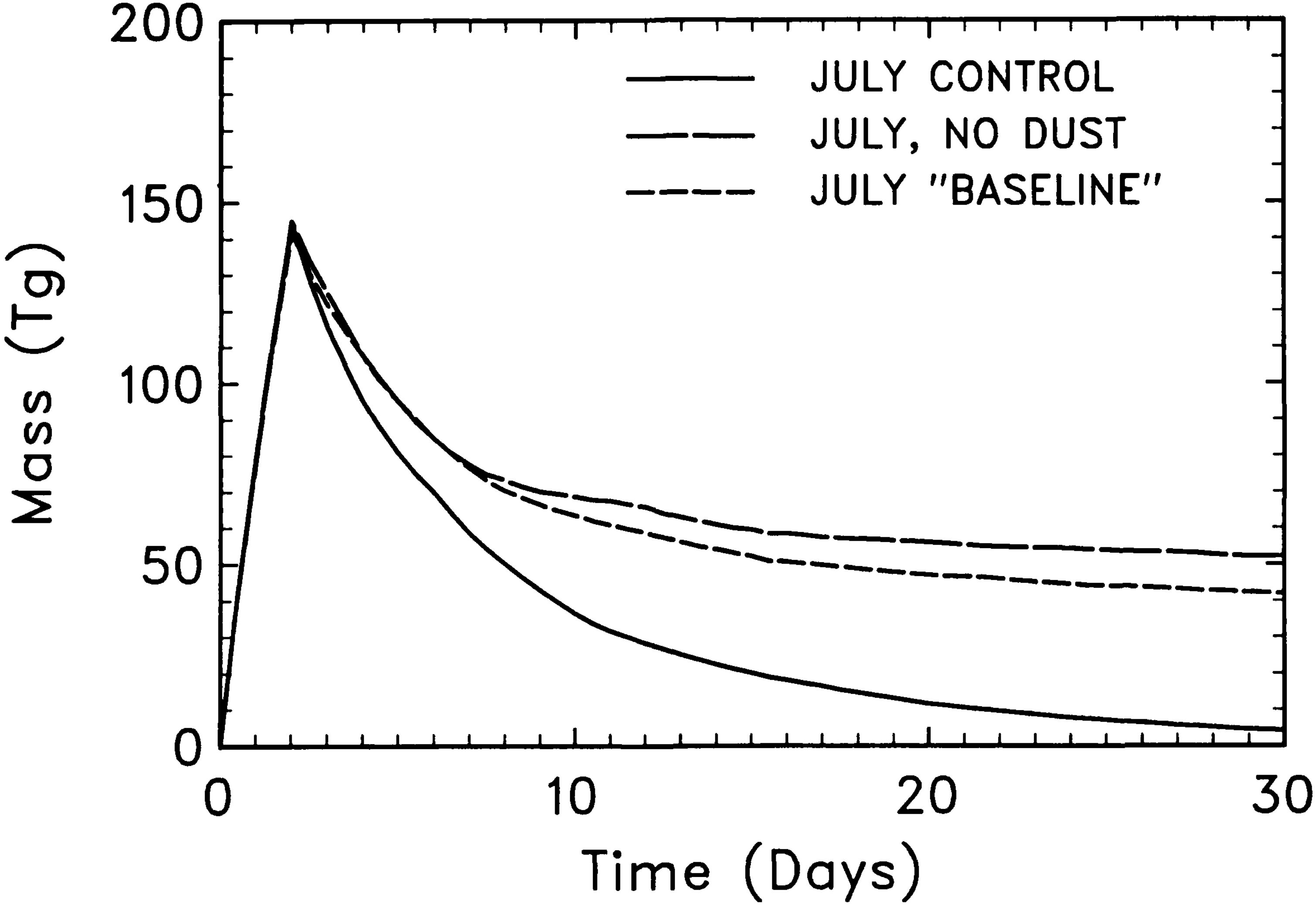


1·0
2·8
3·15
3·5
4·0
4·5
2·2
2·0
1·1
1·8
1·25
1·4
1·6


Zonally Averaged Planetary Albedo
"MEDIUM" SMOKE
JULY: DAYS 10-15
FIXED RADIUS = 0.2μm
INTERACTIVE OPTICAL PROPERTIES
Albedo
1.00
0.80
0.60
0.40
0.20
0.00
90
45
0
-45
Latitude


Zonally Averaged Planetary Albedo
JULY: DAYS 10-15
CONTROL
NO DUST
"BASELINE" DUST
BASALTIC DUST
EXCURSION DUST
Albedo
1.00
0.80
0.60
0.40
0.20
0.00
90
45
0
-45
Latitude

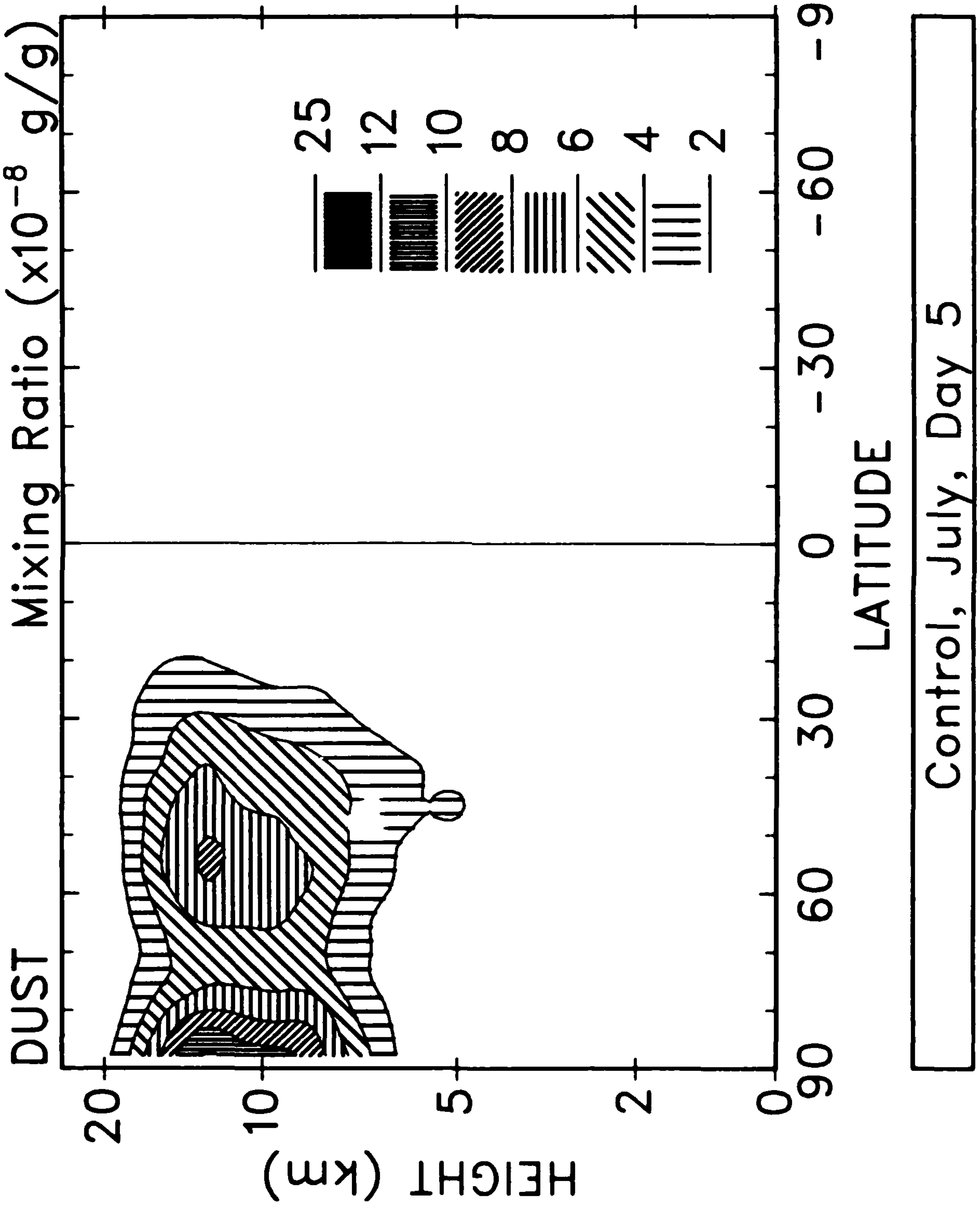
Total Smoke Mass

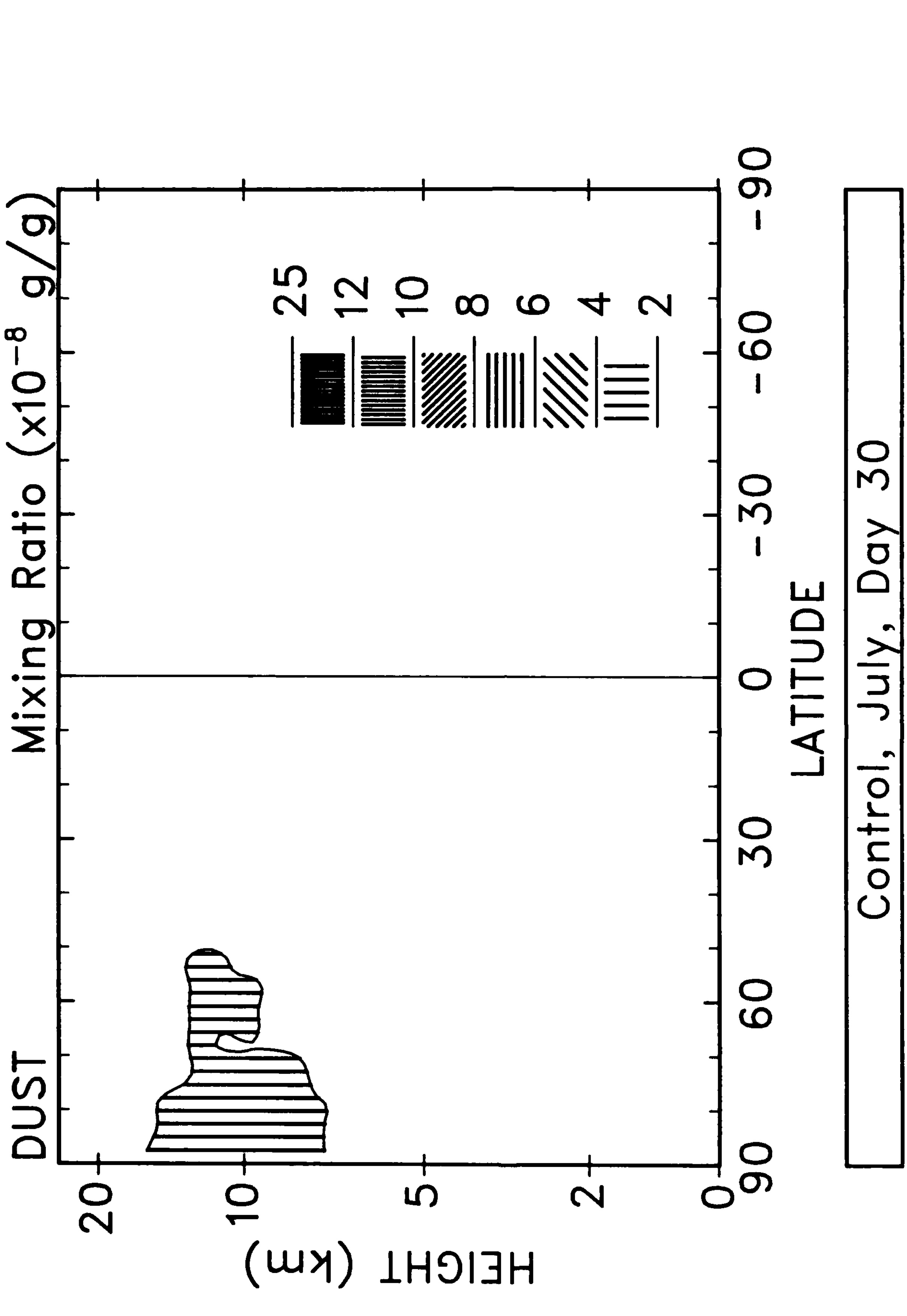


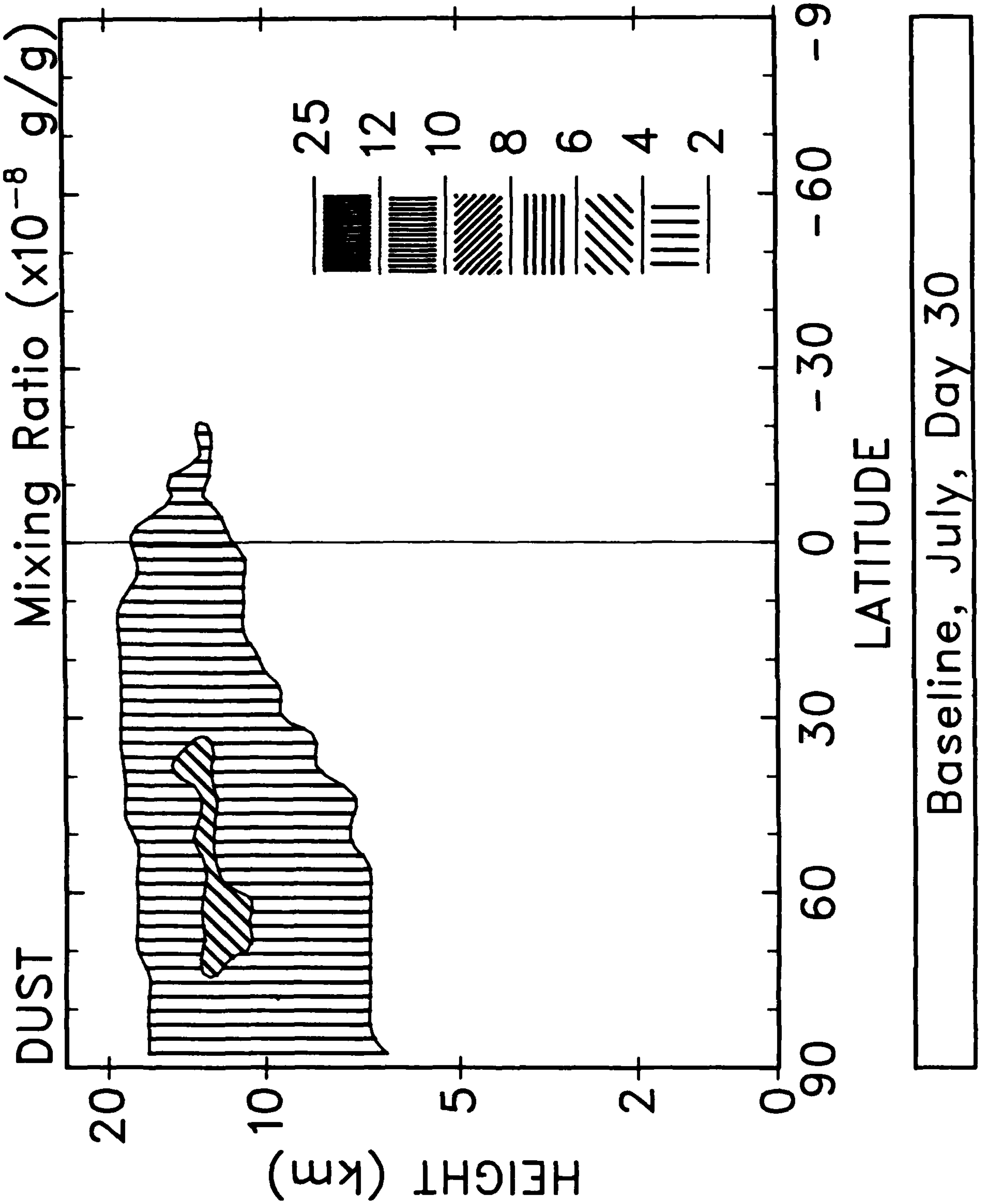
Dust-Associated Suppression of Smoke Lofting

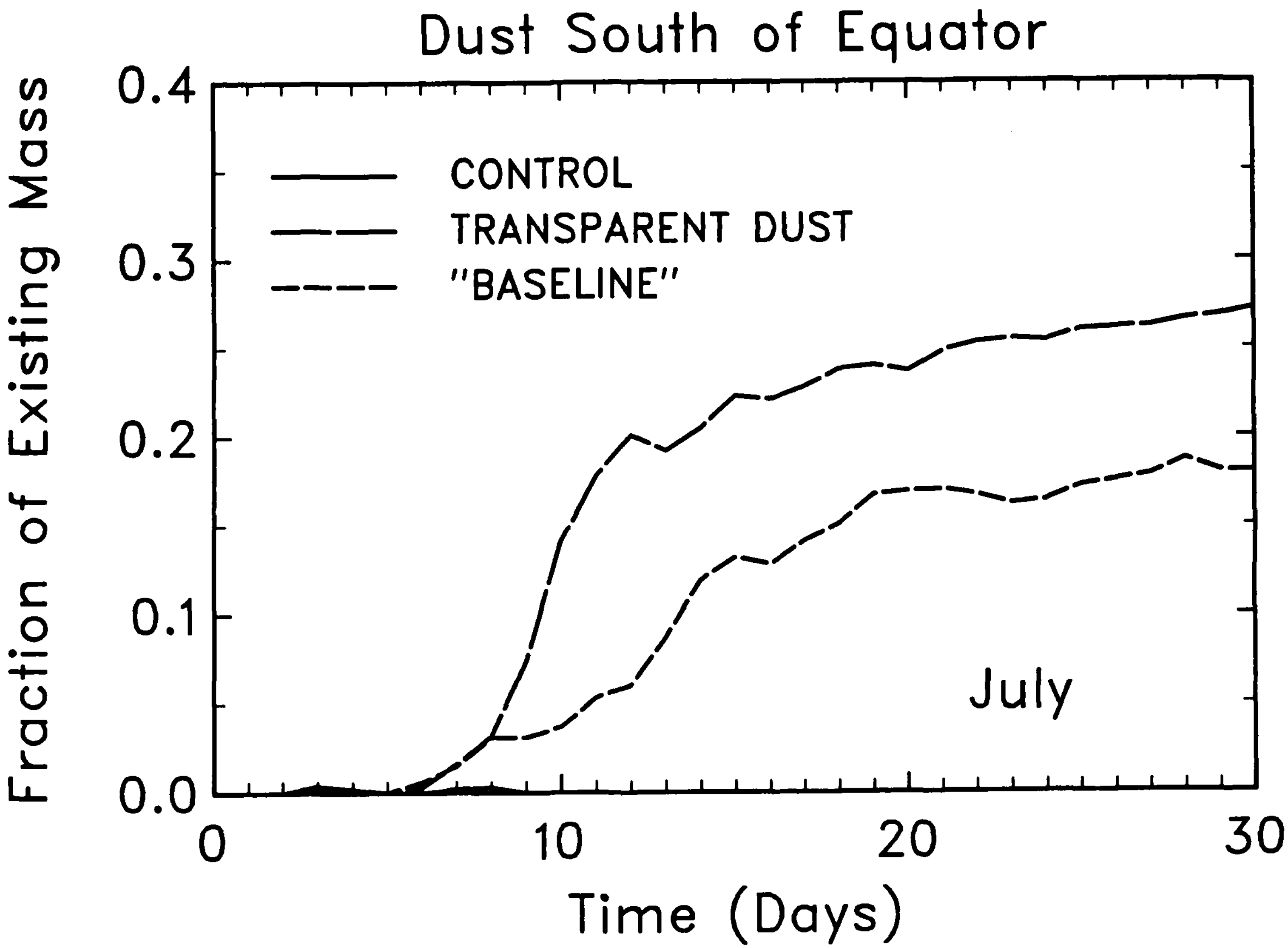
Fraction of Smoke Above 10 km
On Day 15

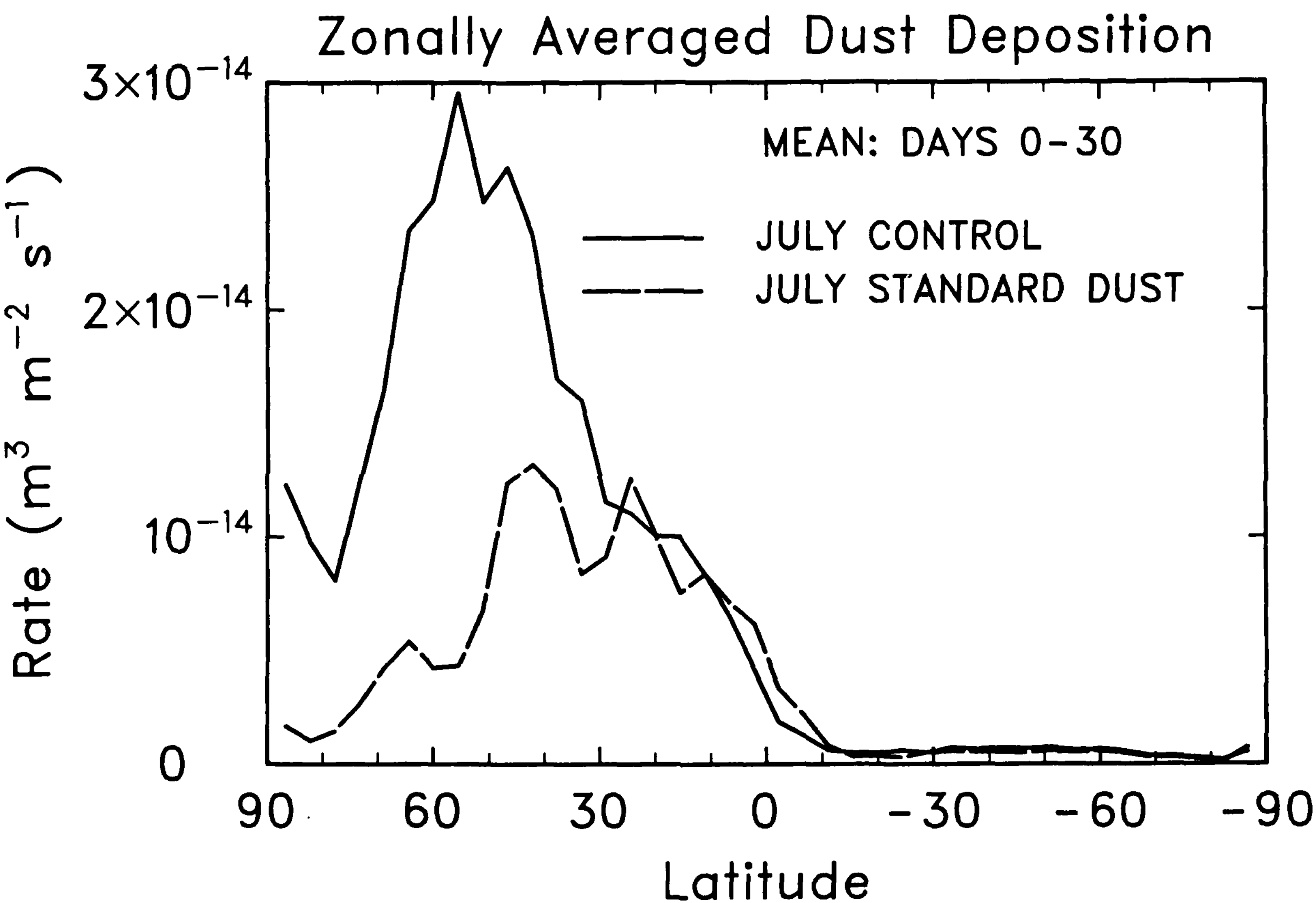
Case	Percentage
No Dust	40
40 Tg Basaltic, $r_g=0.25\mu m$	32
40 Tg Basaltic, $r_g=0.10\mu m$	25
88 Tg Excursion	12
Control	2

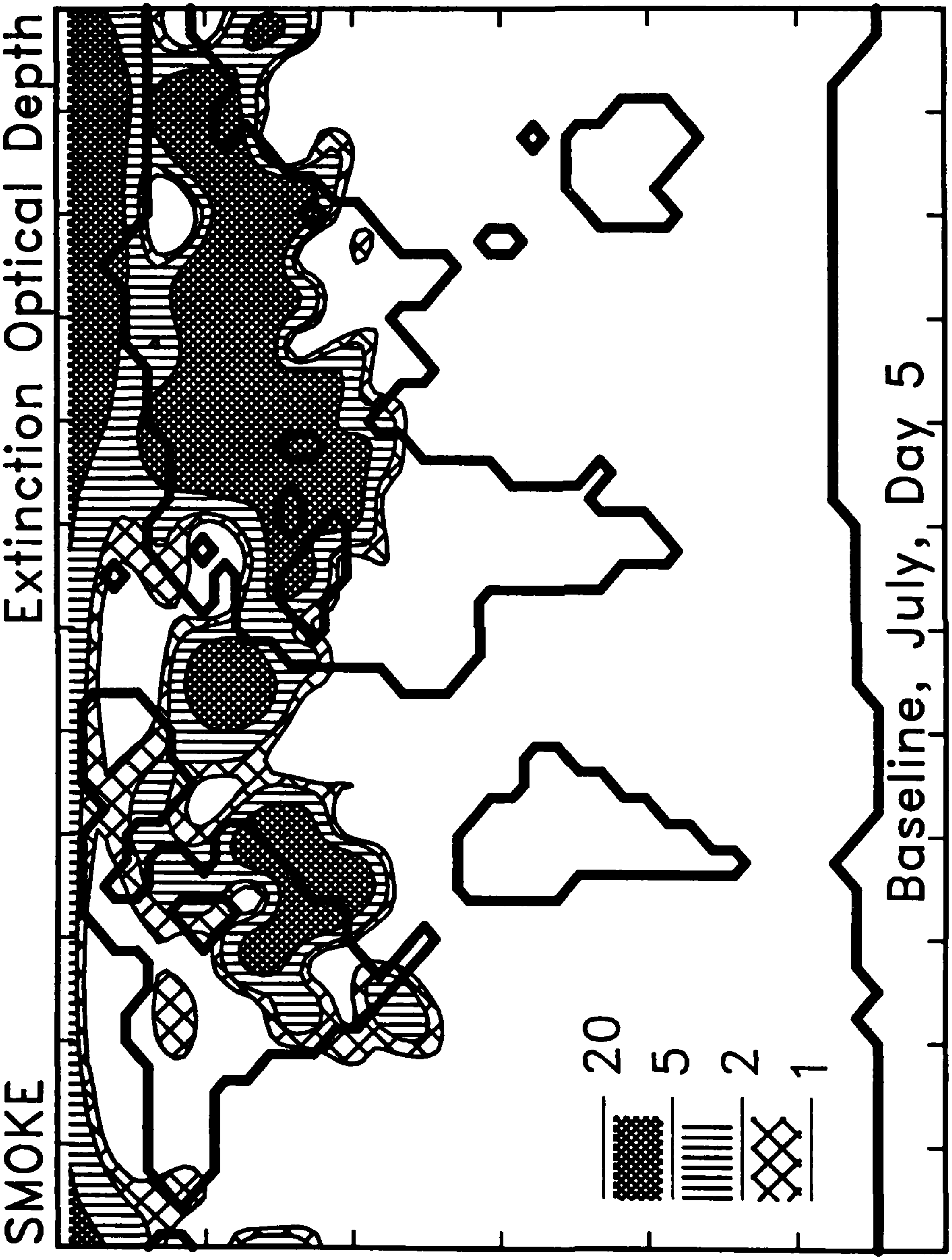

DUST
Mixing Ratio (x10^{-8} g/g)
25
12
10
8
6
4
2
HEIGHT (km)
20
10
5
2
0
90
60
30
0
-30
-60
-90
LATITUDE
Control, July, Day 5

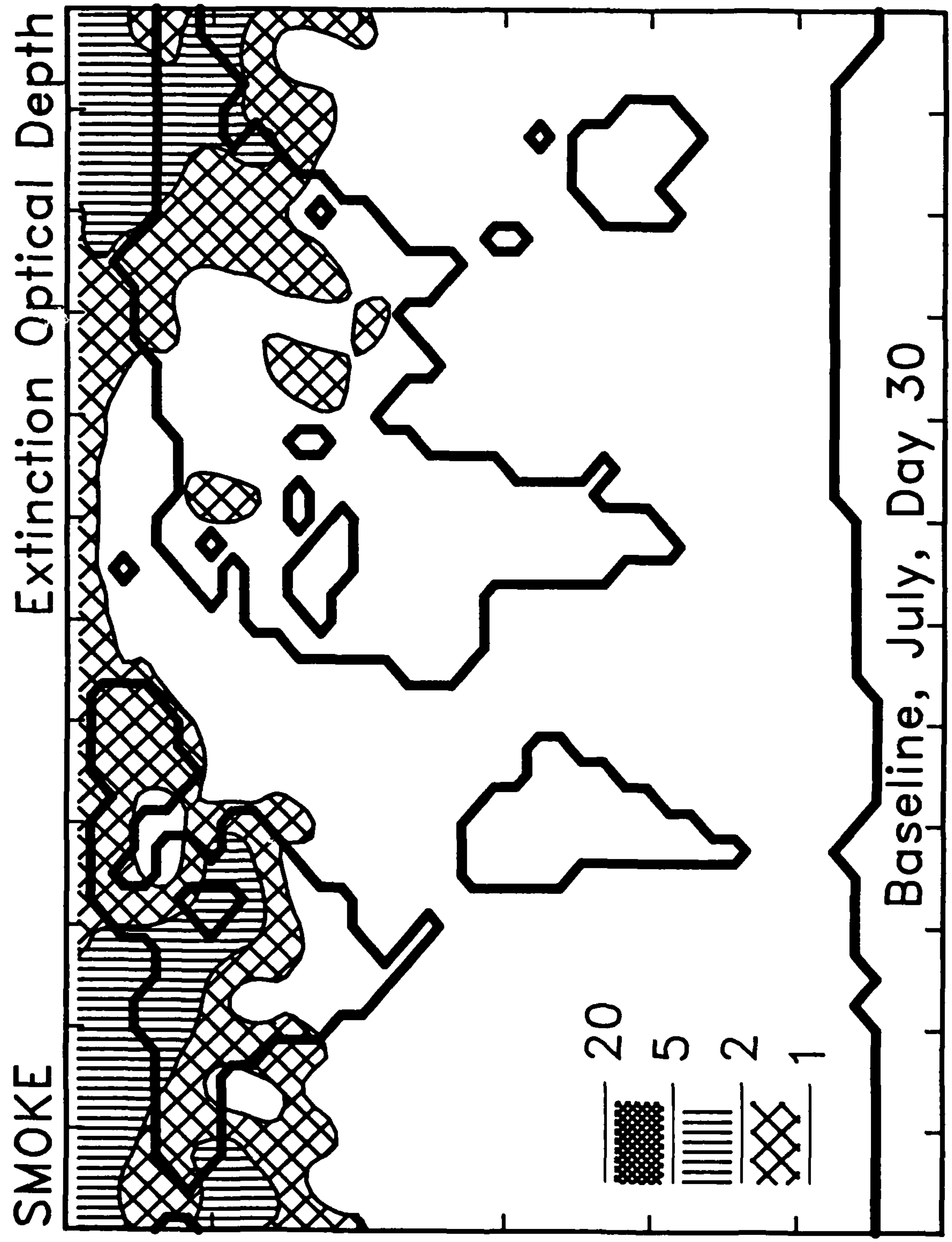

DUST
Mixing Ratio (x10^-8 g/g)
HEIGHT (km)
20
10
5
2
0
90
60
30
0
-30
-60
-90
LATITUDE
25
12
10
8
6
4
2
Control, July, Day 30

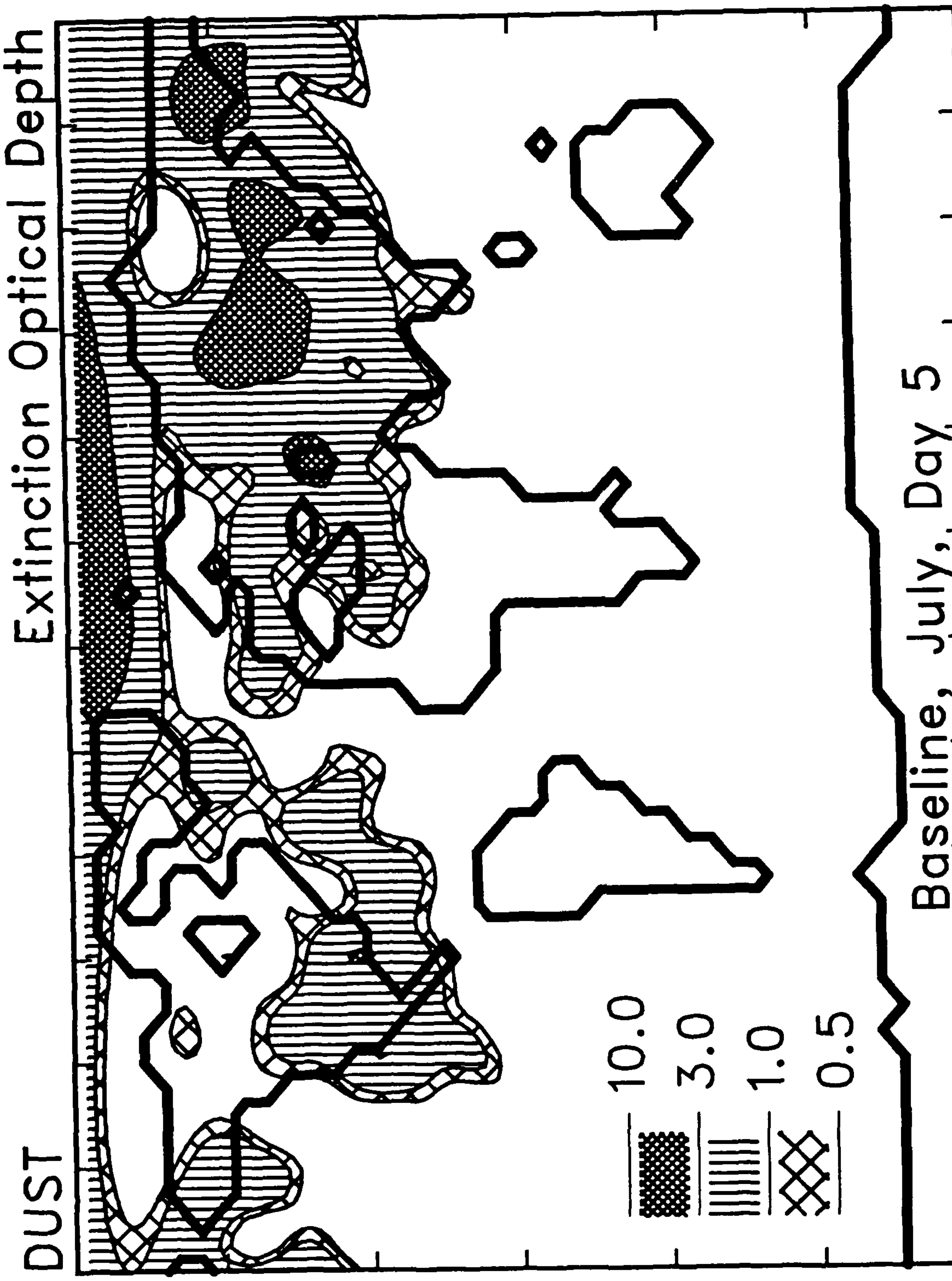

DUST
Mixing Ratio (x10⁻⁸ g/g)
25
12
10
8
6
4
2
HEIGHT (km)
20
10
5
2
0
90
60
30
0
-30
-60
-90
LATITUDE
Baseline, July, Day 30

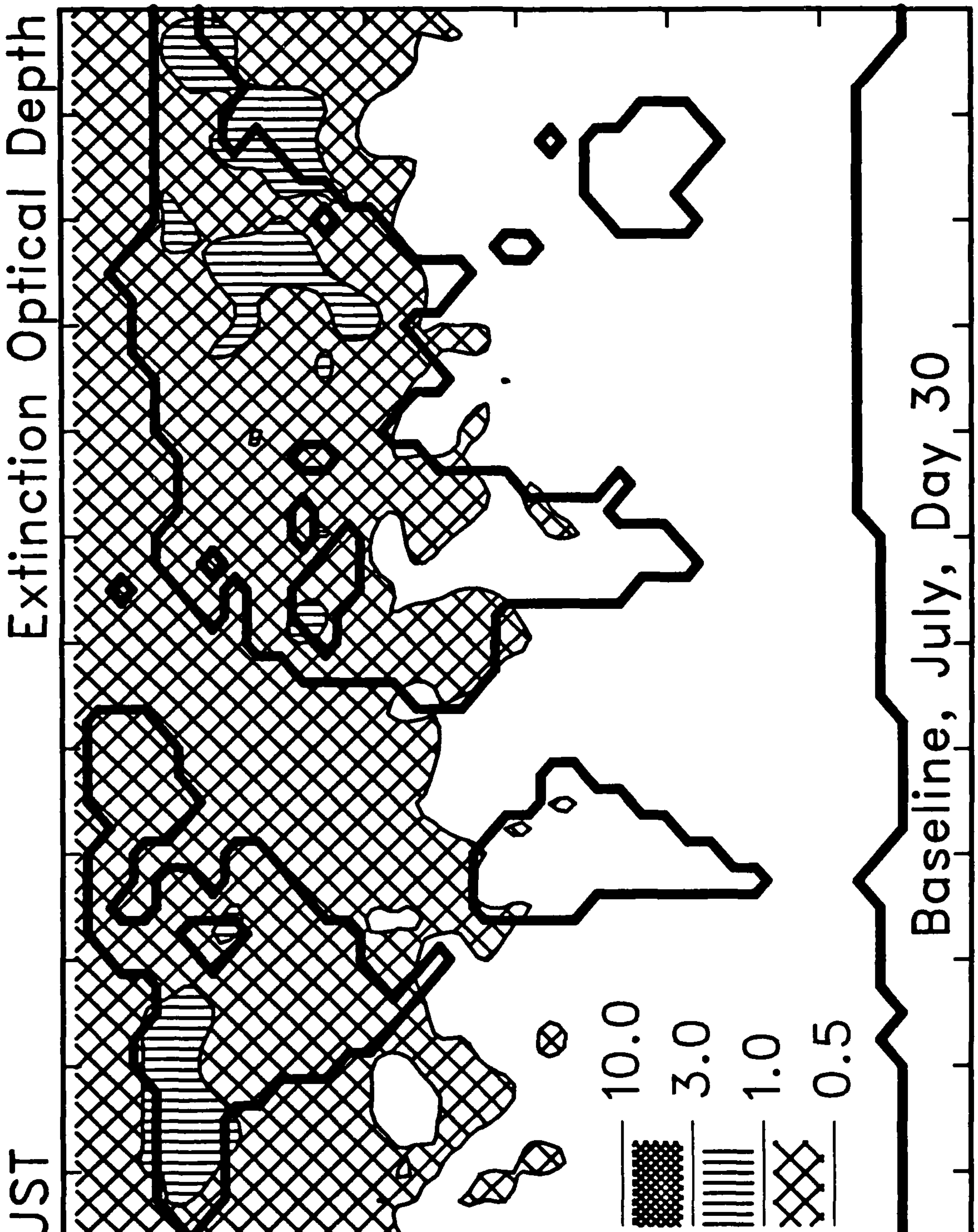

Dust South of Equator
Fraction of Existing Mass
0.4
0.3
0.2
0.1
0.0
0
10
20
30
Time (Days)
CONTROL
TRANSPARENT DUST
"BASELINE"
July


Zonally Averaged Dust Deposition
MEAN: DAYS 0-30
JULY CONTROL
JULY STANDARD DUST
Rate (m^3 m^{-2} s^{-1})
3×10^{-14}
2×10^{-14}
10^{-14}
0
90
60
30
0
-30
-60
-90
Latitude

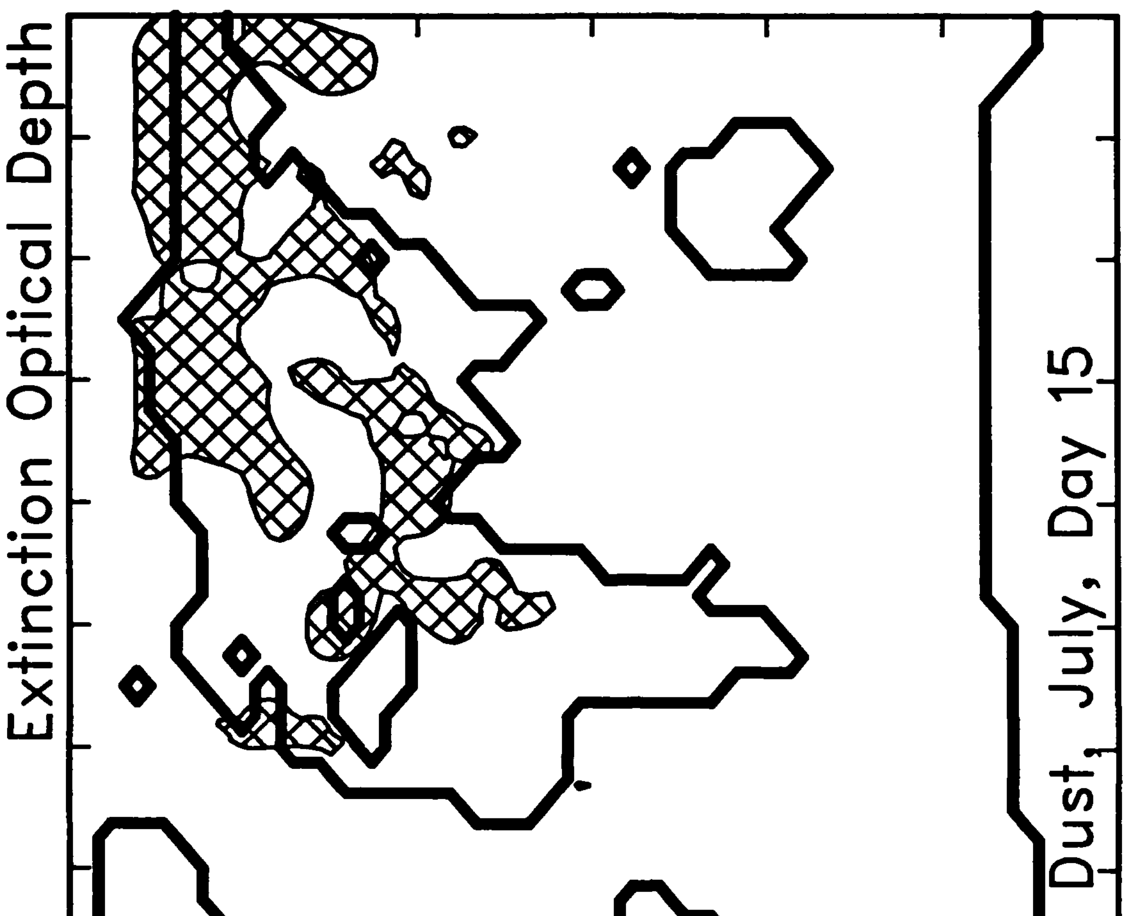

SMOKE
Extinction Optical Depth
20
5
2
1
Baseline, July, Day 5


SMOKE
Extinction Optical Depth
20
5
2
1
Baseline, July, Day 30

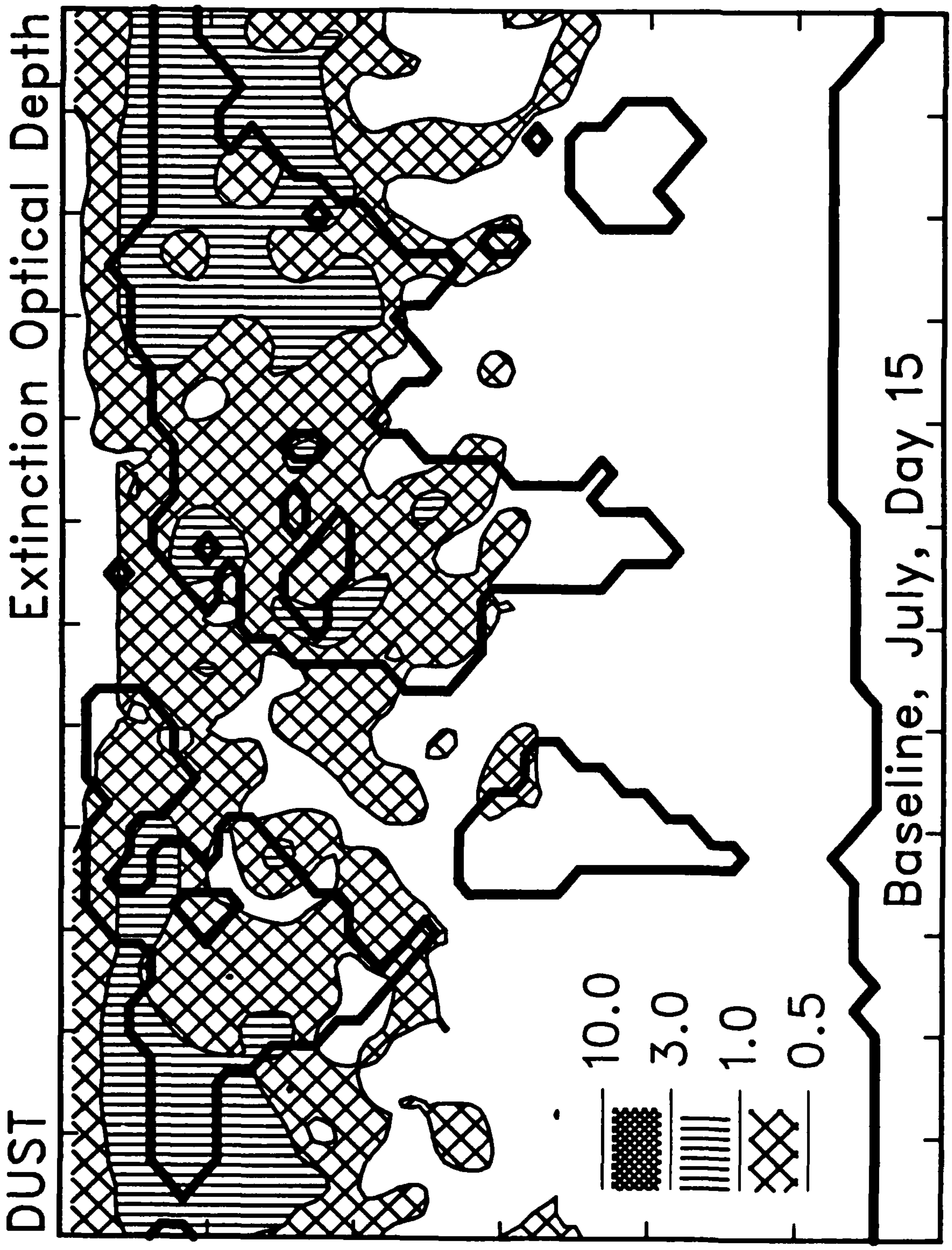

DUST
Extinction Optical Depth
Baseline, July, Day 5
10.0
3.0
1.0
0.5

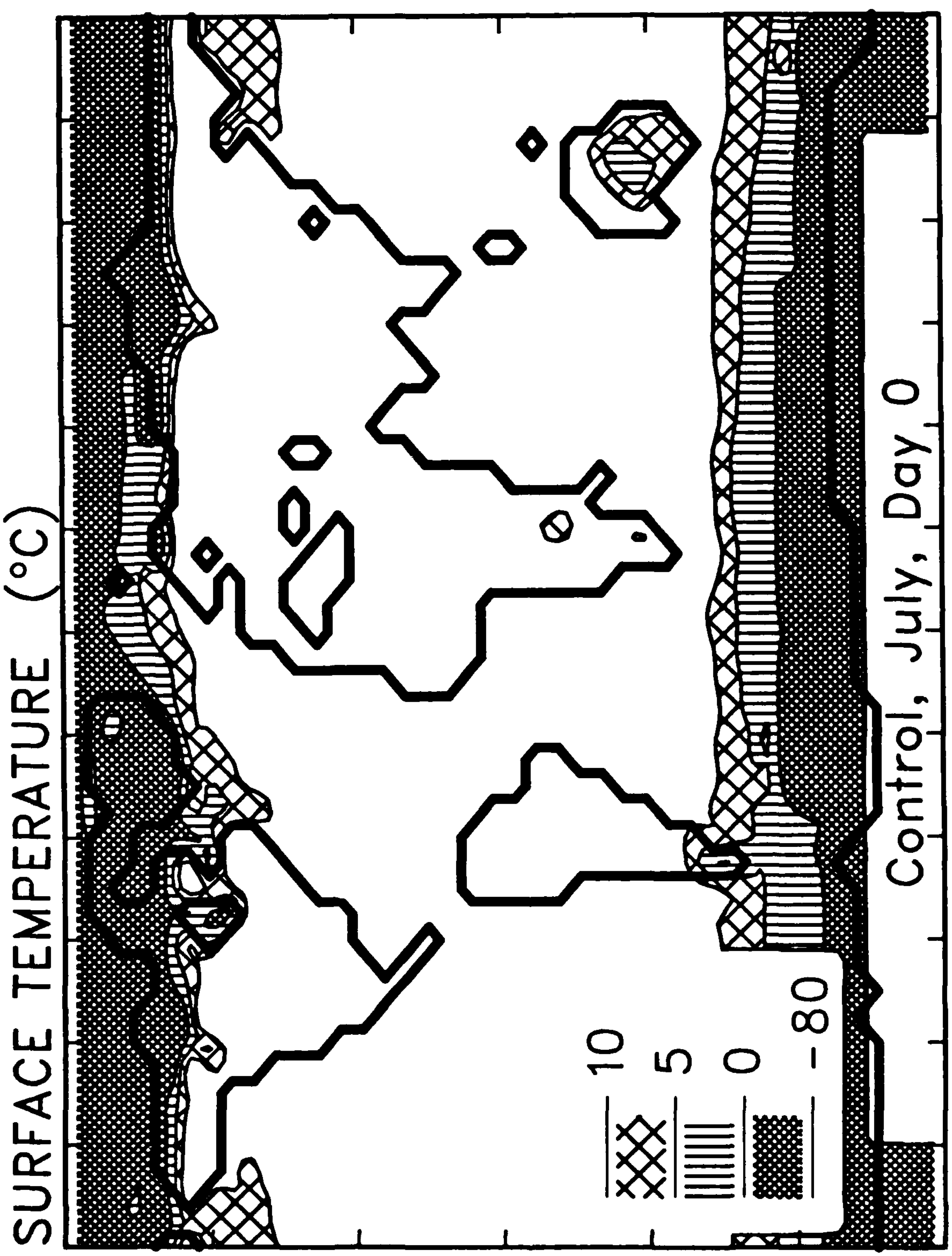


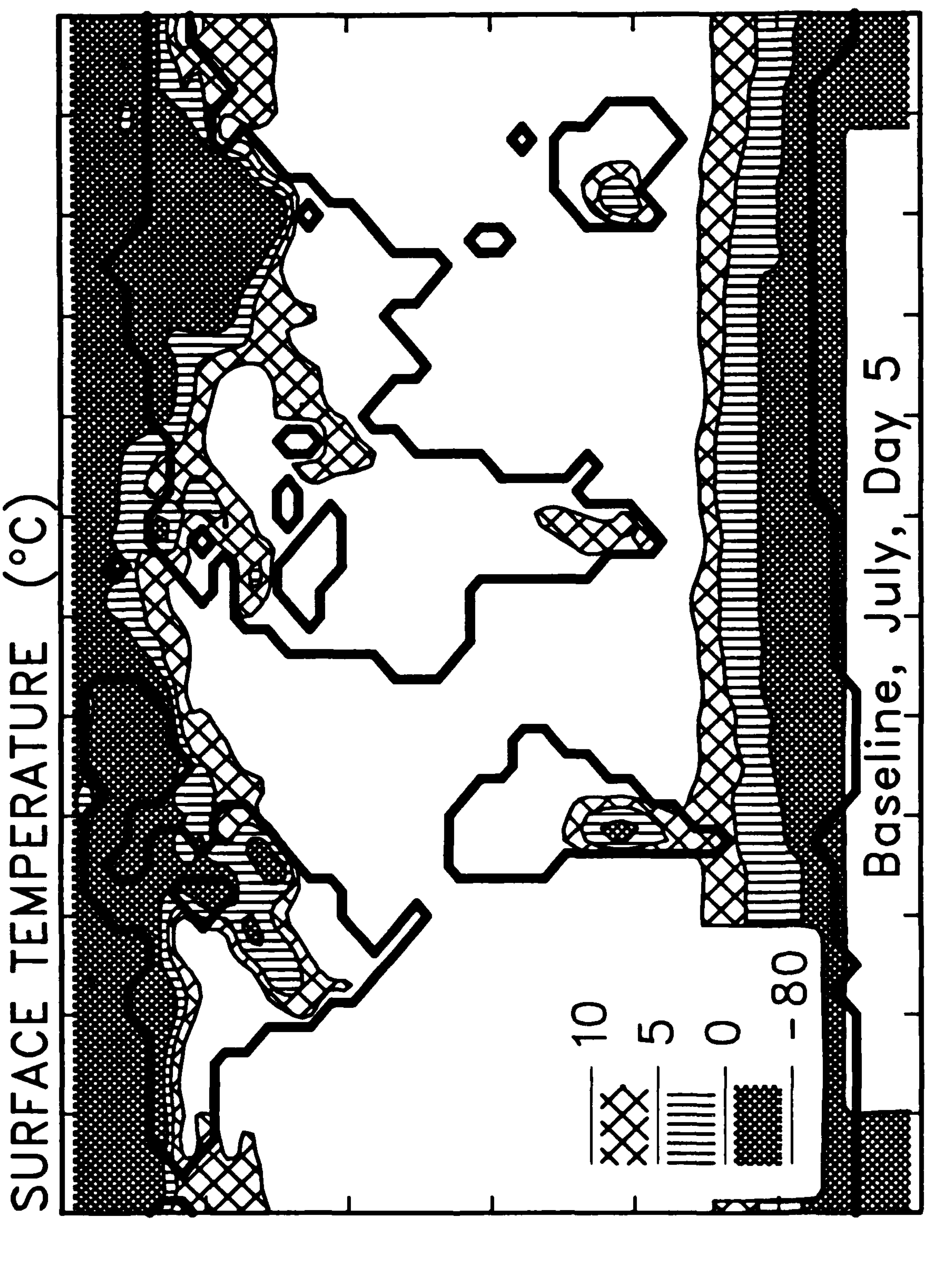
DUST
Extinction Optical Depth
10.0
3.0
1.0
0.5
Baseline, July, Day 30



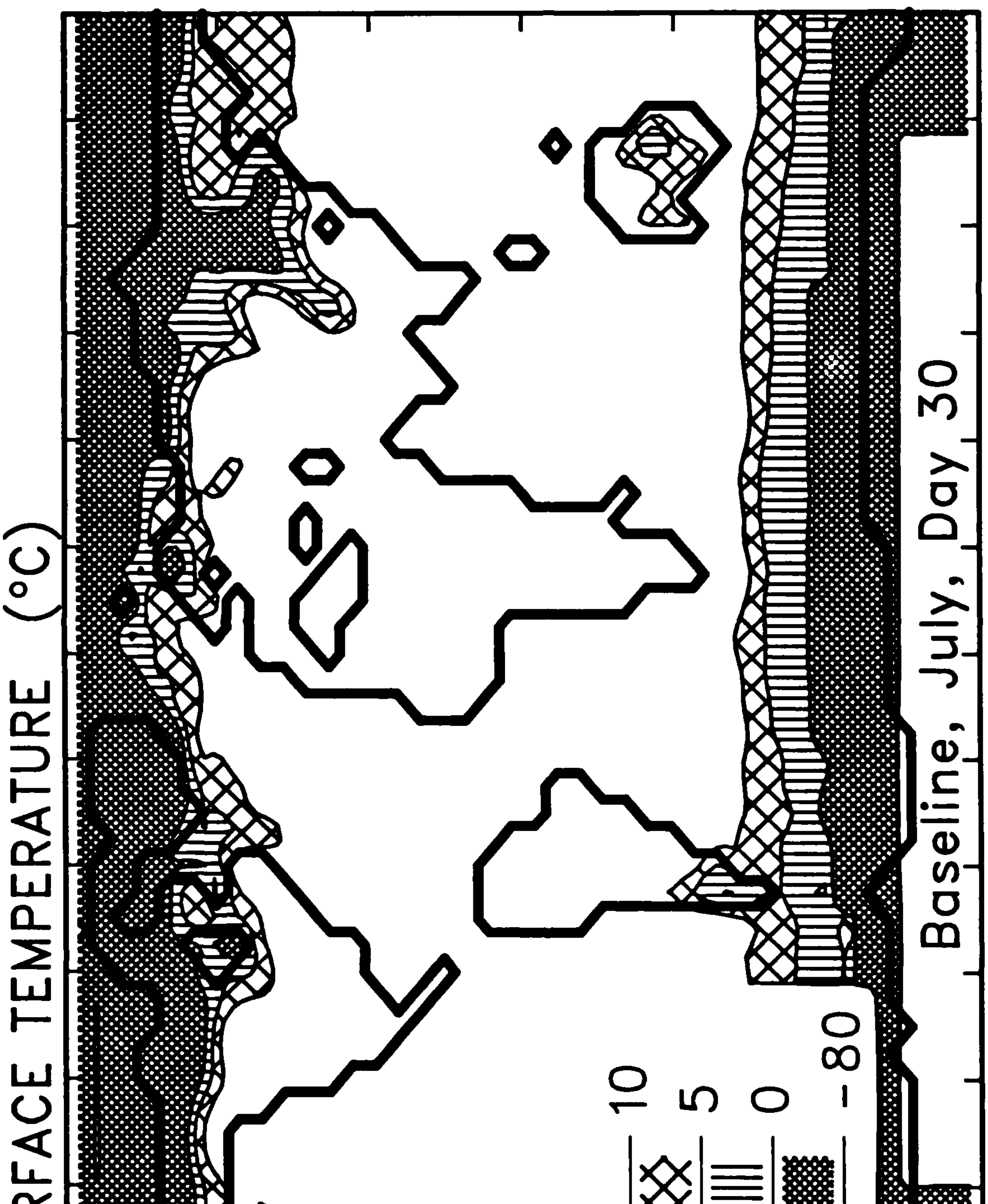
DUST
Extinction Optical Depth
10.0
3.0
1.0
0.5
Basaltic Dust, July, Day 15

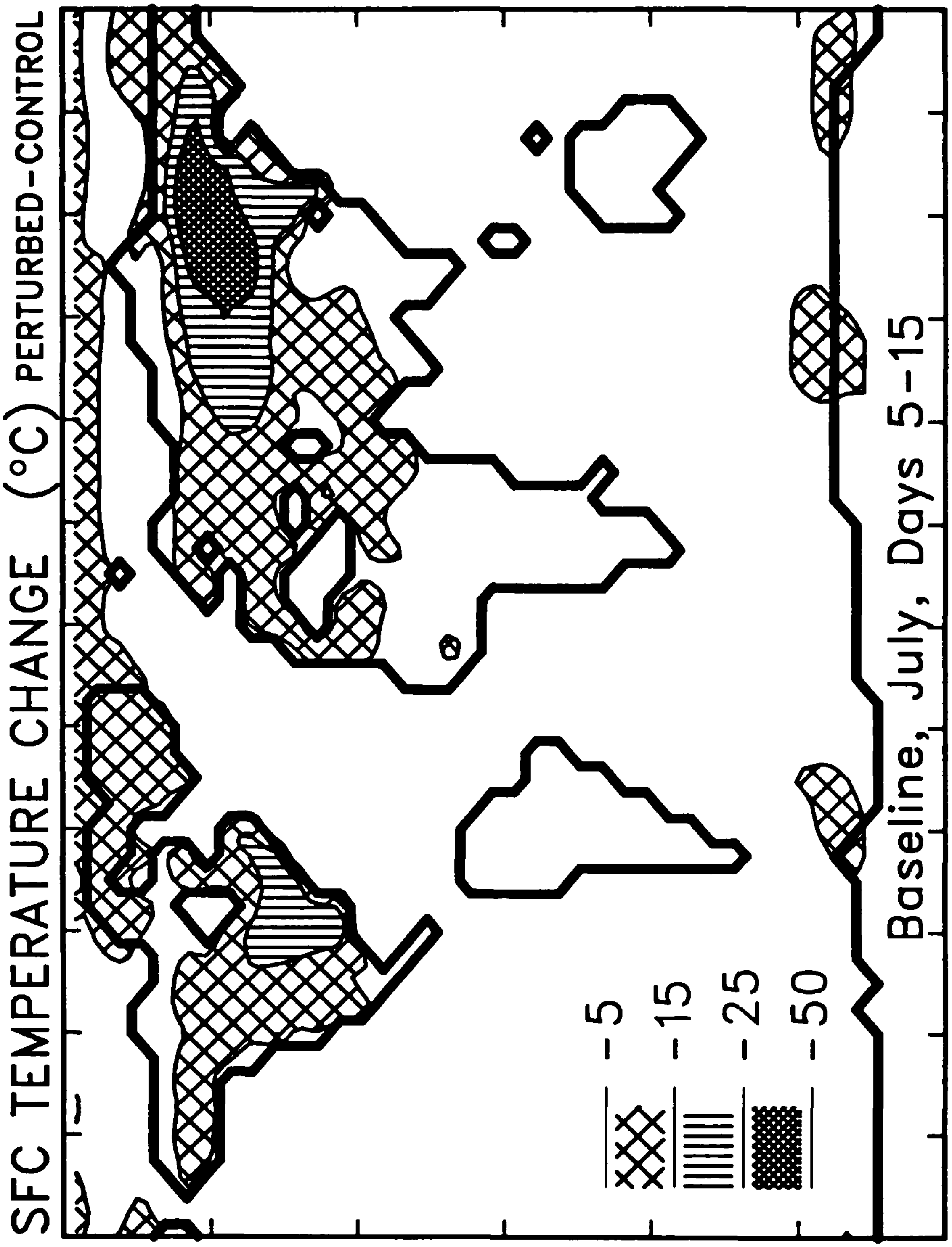

DUST
Extinction Optical Depth
Baseline, July, Day 15
10.0
3.0
1.0
0.5


SURFACE TEMPERATURE (°C)
10
5
0
-80
Control, July, Day 0

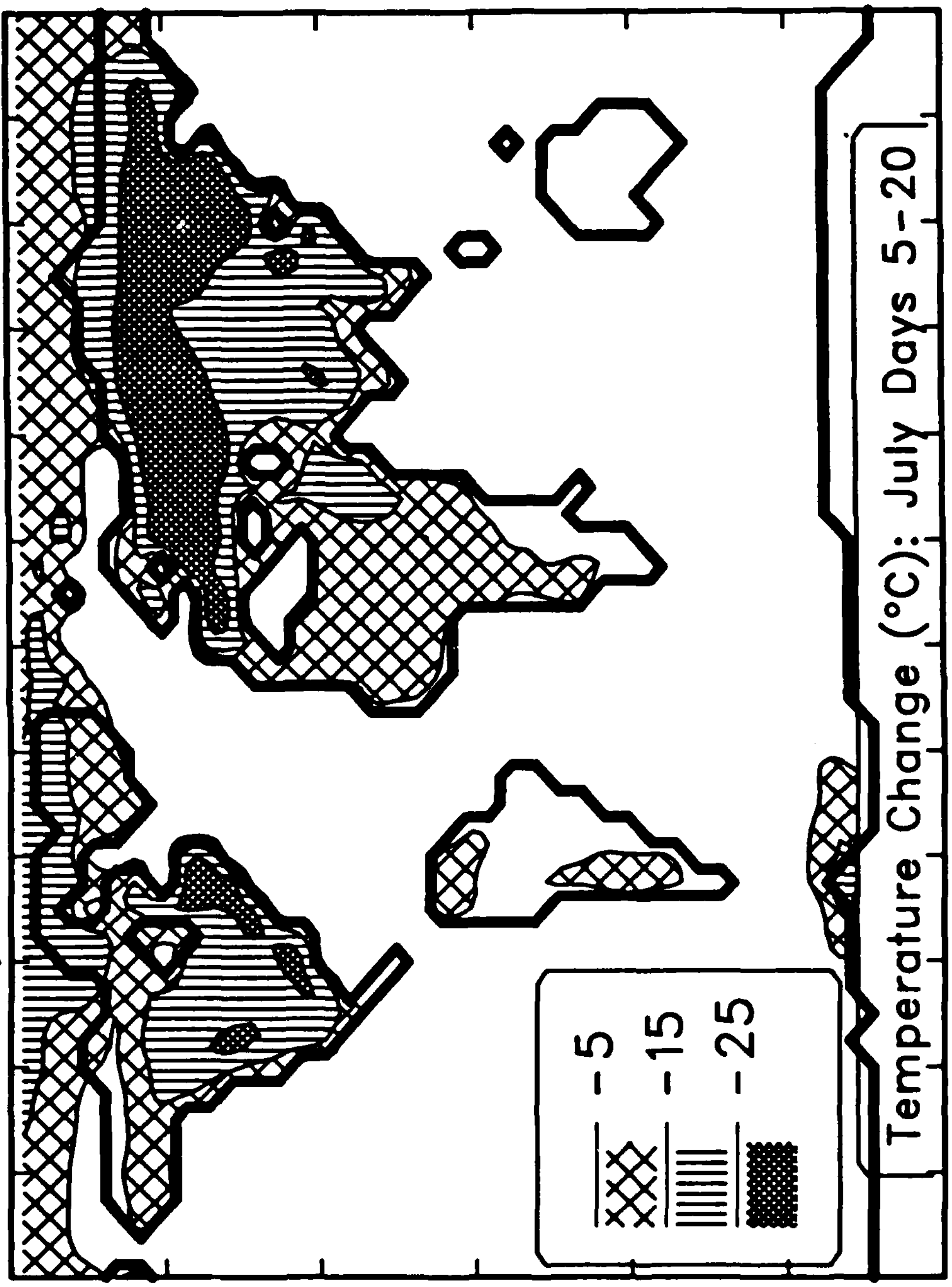


SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline, July, Day 5

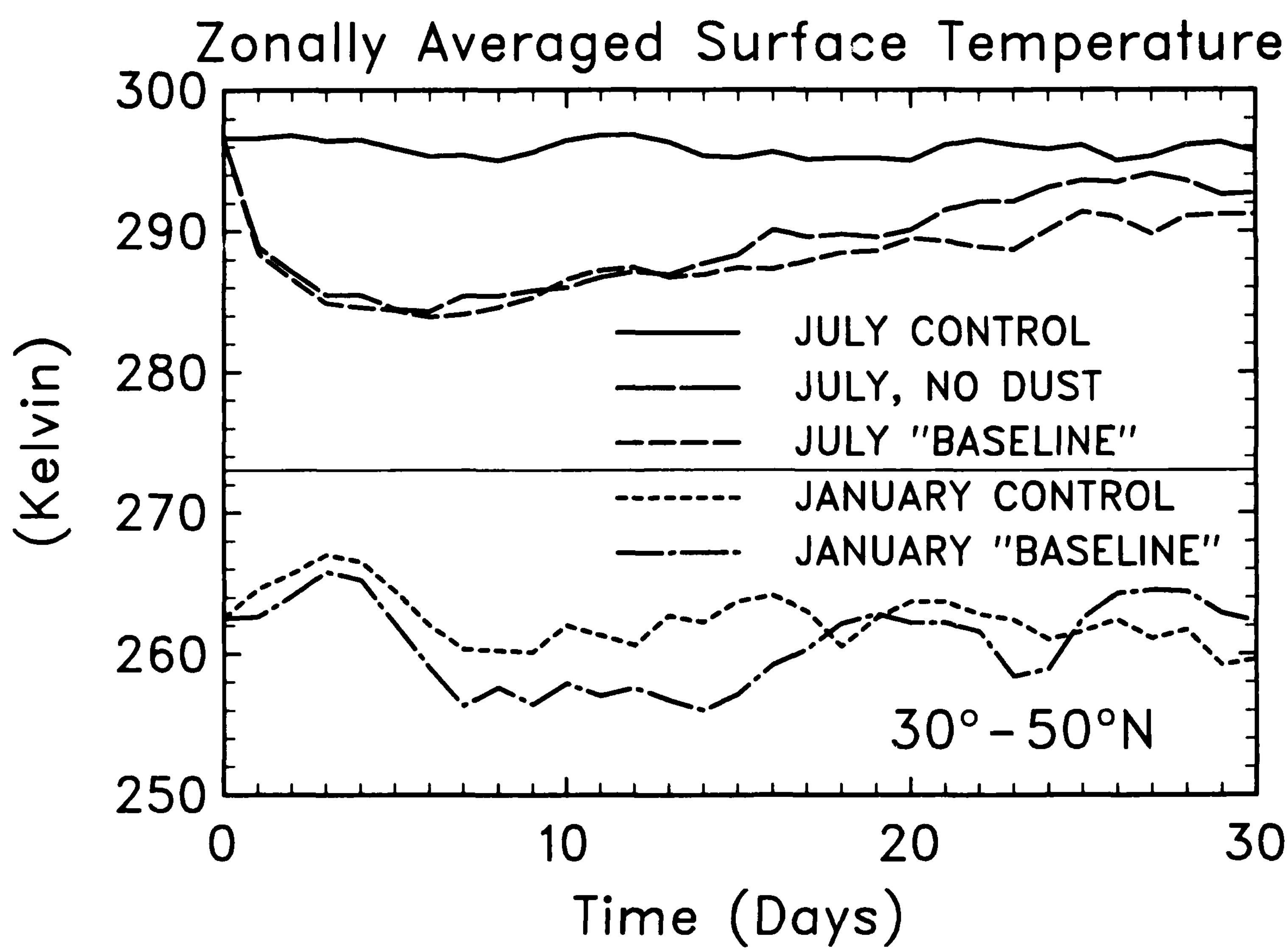

SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline, July, Day 30

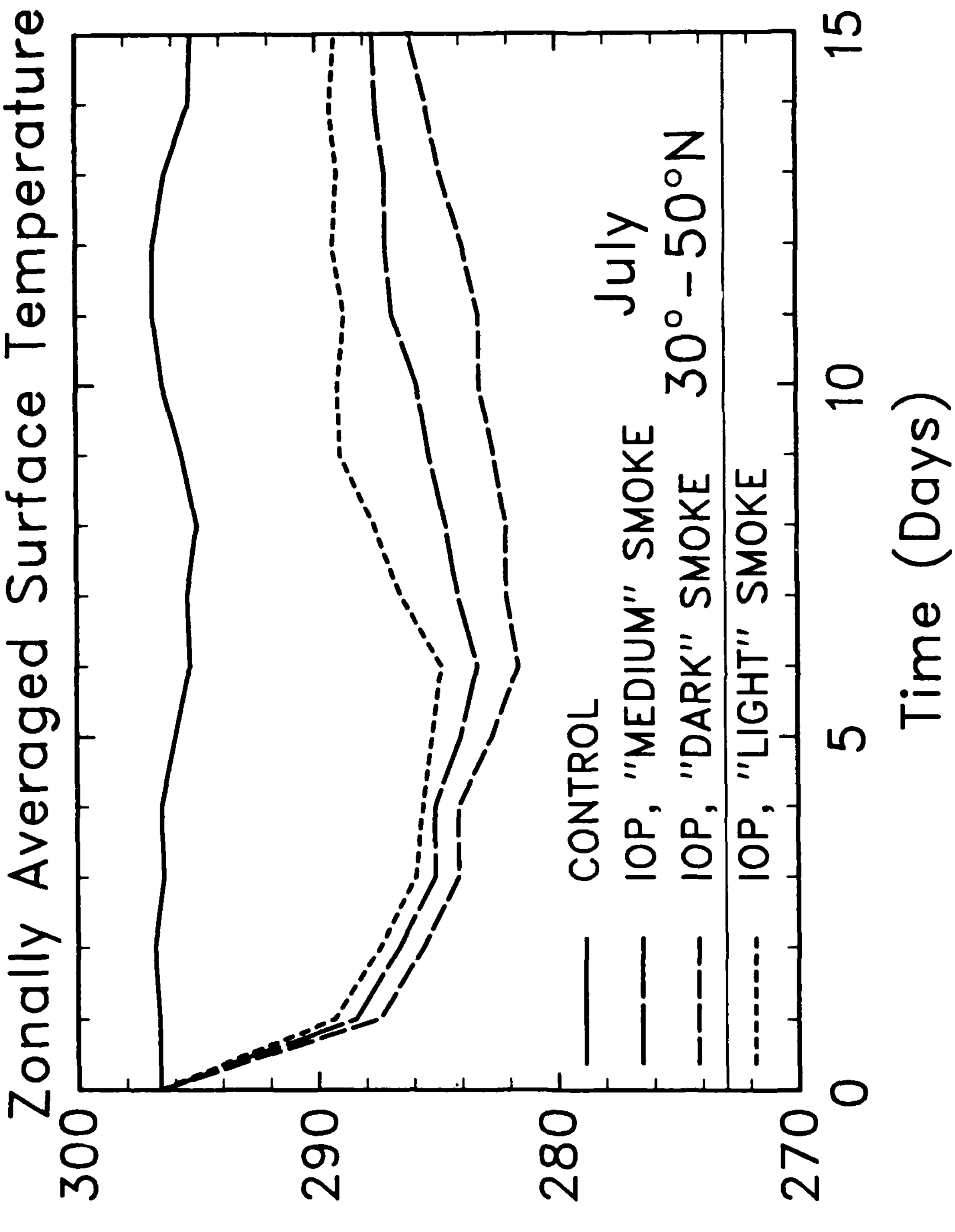

SFC TEMPERATURE CHANGE (°C) PERTURBED-CONTROL
-5
-15
-25
-50
Baseline, July, Days 5-15

No Removal, No Aerosol IR

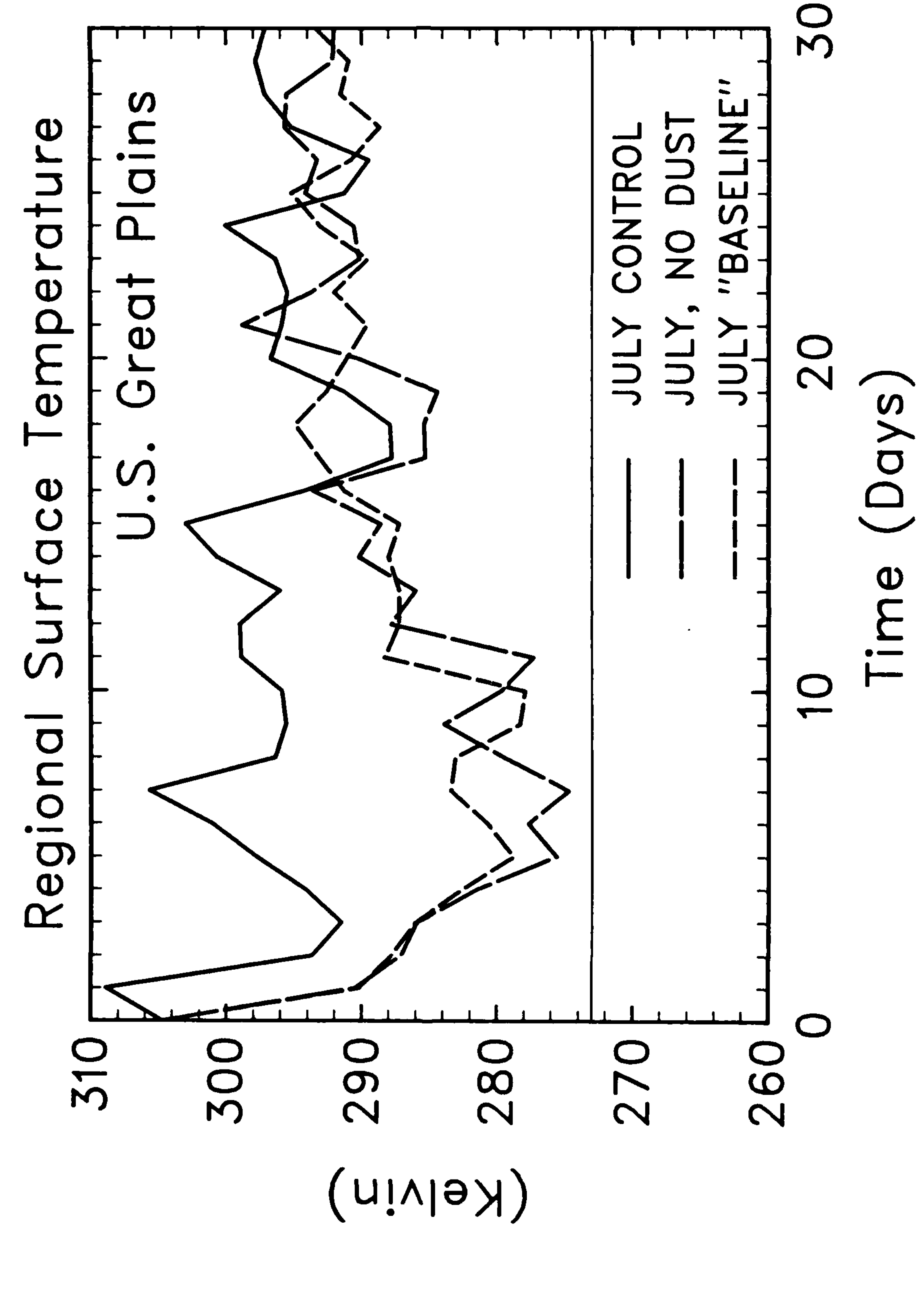


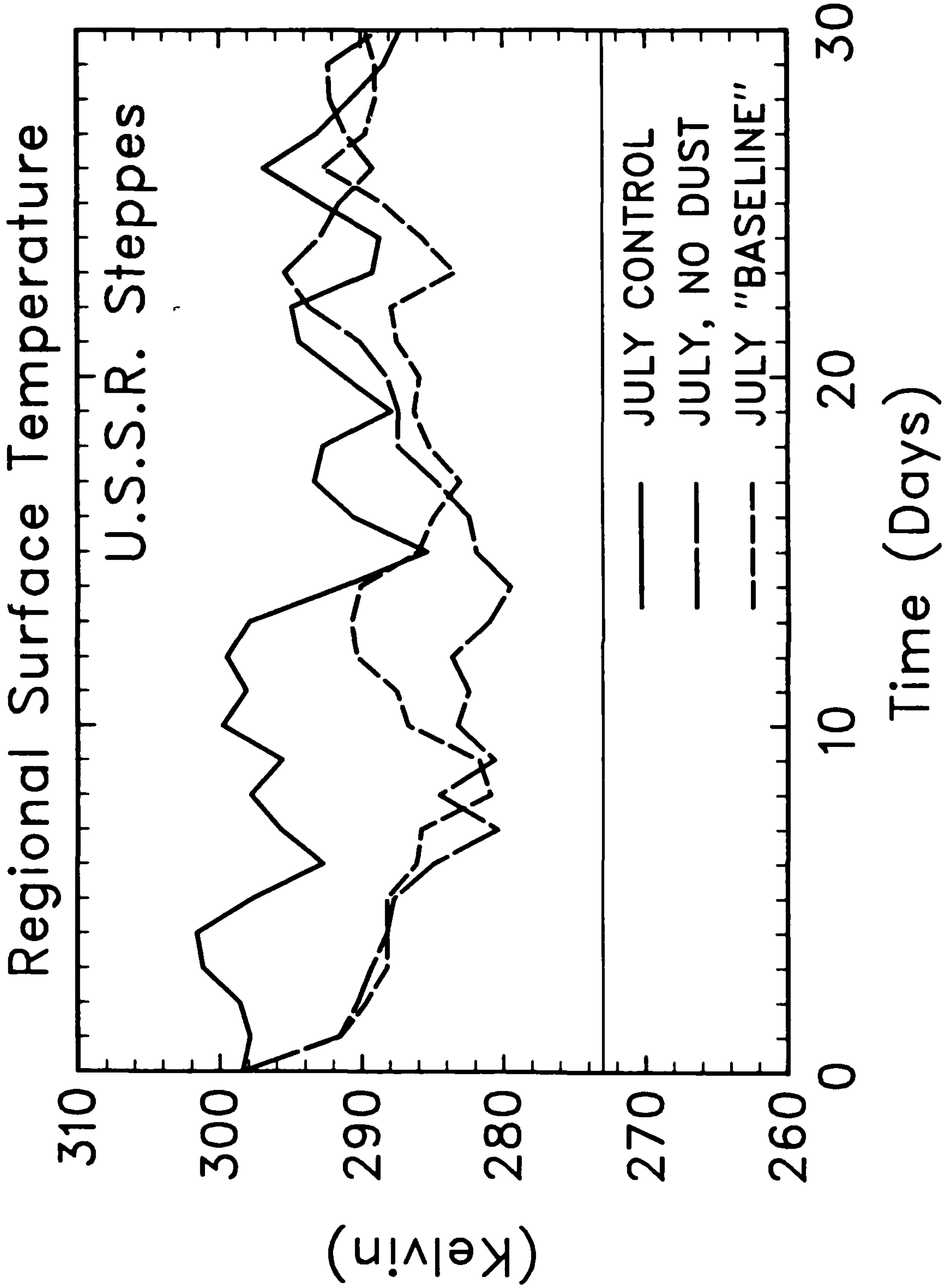
Temperature Change (°C): July Days 5–20


Zonally Averaged Surface Temperature
300
290
280
270
260
250
(Kelvin)
0
10
20
30
Time (Days)
JULY CONTROL
JULY, NO DUST
JULY "BASELINE"
JANUARY CONTROL
JANUARY "BASELINE"
30°-50°N

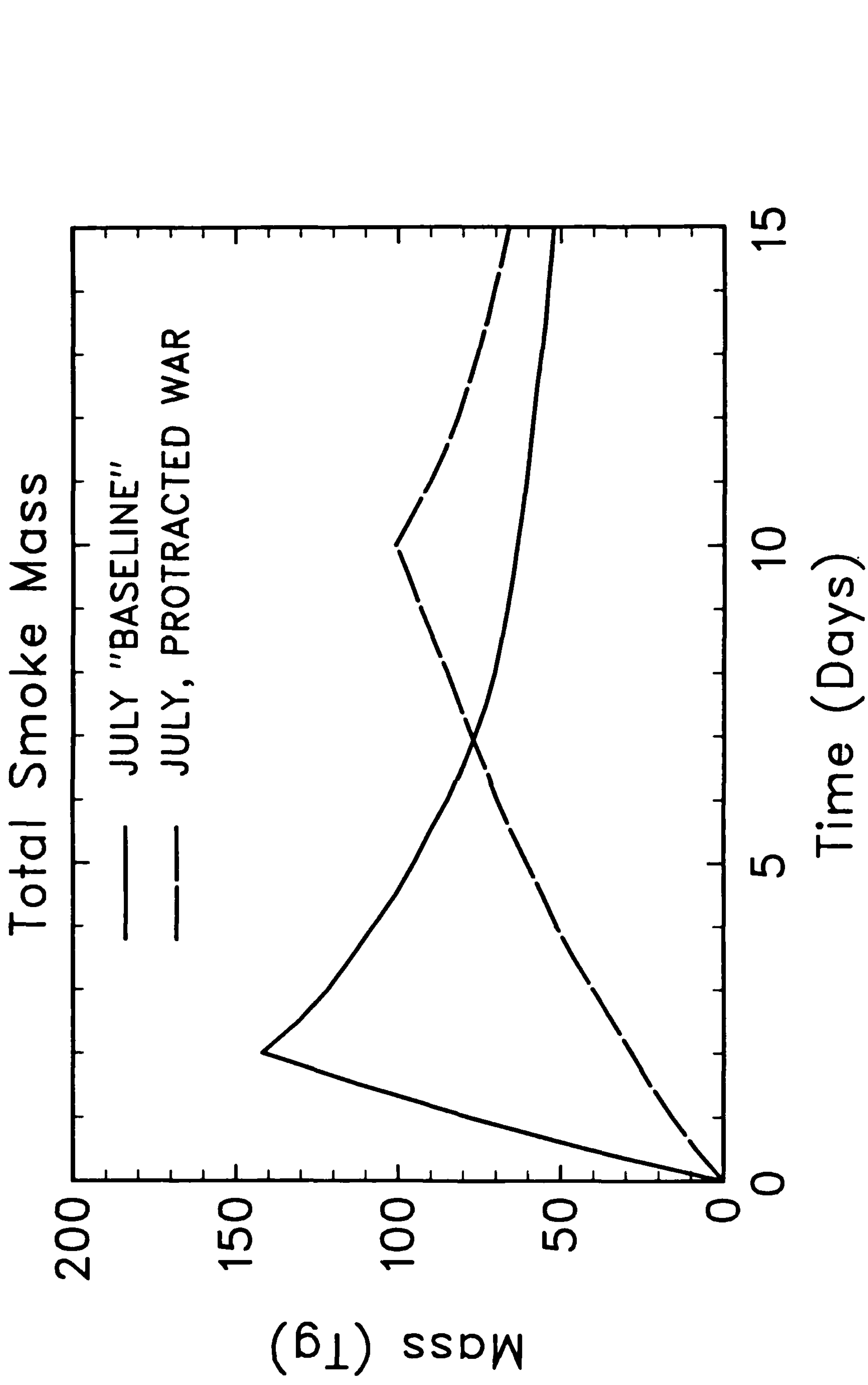


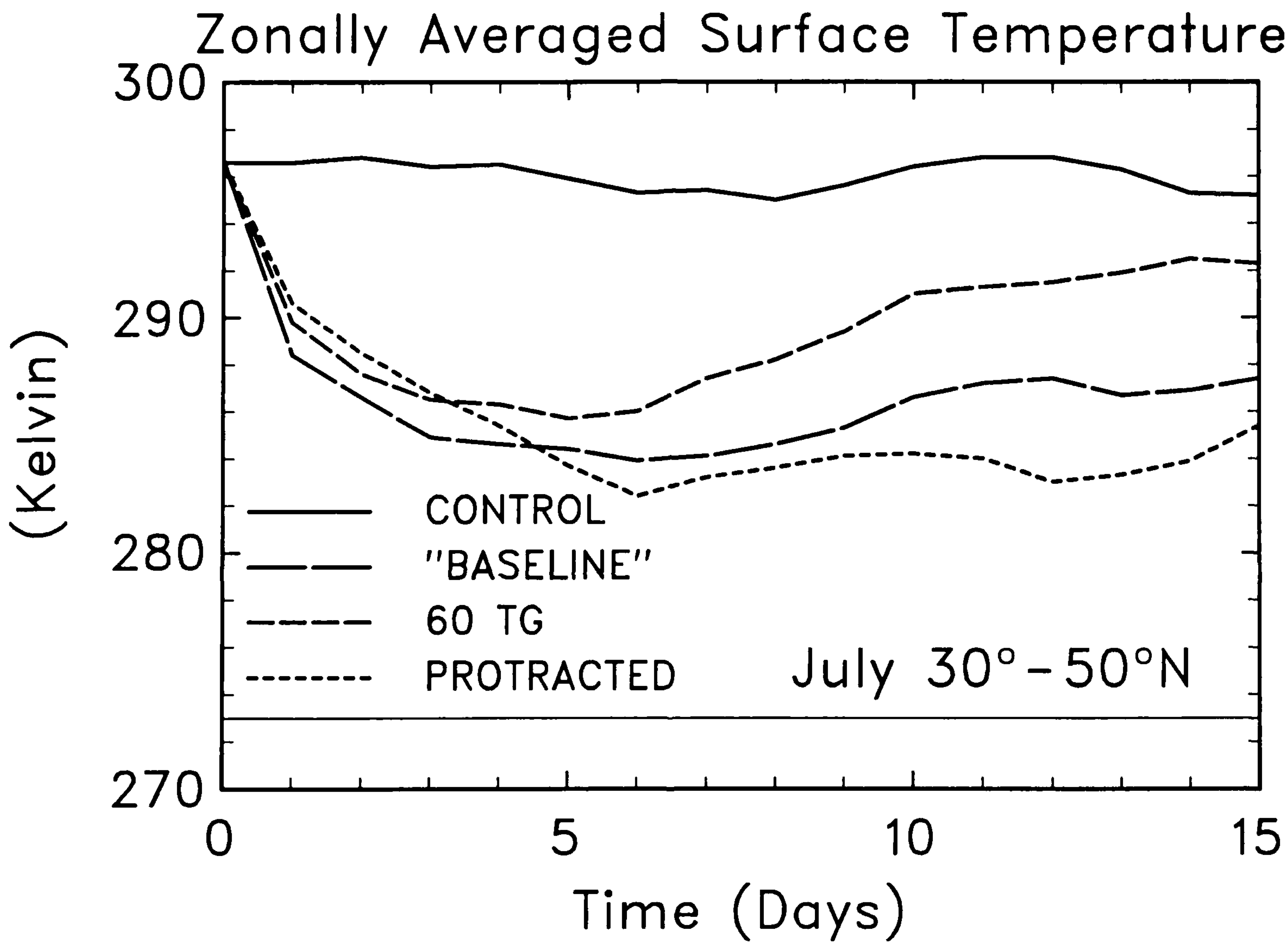
Zonally Averaged Surface Temperature
(Kelvin)
300
290
280
270
0
5
10
15
Time (Days)
July
30°–50°N
CONTROL
IOP, "MEDIUM" SMOKE
IOP, "DARK" SMOKE
IOP, "LIGHT" SMOKE


Regional Surface Temperature
U.S. Great Plains
(Kelvin)
310
300
290
280
270
260
0
10
20
30
Time (Days)
JULY CONTROL
JULY, NO DUST
JULY "BASELINE"



Regional Surface Temperature
U.S.S.R. Steppes
(Kelvin)
310
300
290
280
270
260
0
10
20
30
Time (Days)
JULY CONTROL
JULY, NO DUST
JULY "BASELINE"


Total Smoke Mass
JULY "BASELINE"
JULY, PROTRACTED WAR
Mass (Tg)
200
150
100
50
0
0
5
10
15
Time (Days)


Zonally Averaged Surface Temperature
300
290
280
270
(Kelvin)
0
5
10
15
Time (Days)
CONTROL
"BASELINE"
60 TG
PROTRACTED
July 30°-50°N

Conclusions From Scattering Sensitivity Tests

For Fixed July Diurnal Mean Sun:

- Plausible range of scattering has little effect on rate of smoke lofting and transport.
- For fixed specific absorption, going from non-scattering to mid-range scattering decreases land surface temperature by about 2°C.
- The range of scattering from plausible variations in smoke composition changes land surface temperature by ±3°C.

Conclusions From IR Sensitivity Tests

July 180 Tg Cases:
With Aerosol IR Opacity Vs. Without

- Nominal aerosol IR opacity mitigates land surface temperture drop by roughly 25%.
- "Grey" absorber approximation for smoke is reasonably accurate if 8–12 μm "window" specific absorption is used for "grey" value.

Simplified History of Temperature Effects

- NCAR Models With 180 Tg Smoke Injection
- Mid-latitude NH Land Surface Temperature

Model	Temperature Change
1-D, Annual	-35°C
3-D, July ...	
Zonal Smoke, No Removal	-18°C
Transport, No Removal	-22°C
Transport, No Removal, Aerosol IR	-15°C
Transport, Removal, Aerosol IR†	-12°C

† Days 5-10

Title: Atmospheric Effects of Nuclear War Aerosols in GCM Simulations: Modeling of Smoke Microphysical Processes

By: Starley Thompson, Filippo Giorgi (National Center for Atmospheric Research)

A comprehensive aerosol scavenging package that includes wet removal, coagulation, sedimentation and dry deposition has been incorporated into a global atmospheric general circulation model (GCM) and has been used in simulations of nuclear war smoke and dust. The parameterization uses a new computationally efficient technique based on predicting the parameters of an assumed particle size distribution rather than dividing the particles in many finite size bins. Initial simulations assume a lognormal size distribution for smoke particles and a fixed particle radius dispersion about the mode size. Thus, only two dependent quantities are needed to completely specify the smoke size distribution, e.g., smoke total mass and mode radius. Dust is treated simply as a distribution having fixed mode radius and size dispersion. Simulations have been performed to determine the sensitivity of the smoke removal rate to initial smoke injection radius and size dispersion. The evolution of smoke radii as a function of time and space are of particular interest since the optical properties of smoke depend on particle size. Results of simulations having full feedback between smoke radii and solar optical properties will be presented.

ATMOSPHERIC EFFECTS OF NUCLEAR-WAR AEROSOLS IN GCM SIMULATIONS: MODELING OF SMOKE MICROPHYSICAL PROCESSES

GENERAL REQUIREMENTS

- Comprehensive aerosol microphysics.

  A model in which the properties of the particle population are prescribed cannot describe the effect of important microphysical processes.

- Computational efficiency.

  A detailed bin model is too expensive for use in GCMs.

- Adopt an intermediate approach.

MODEL-AEROSOL CHARACTERISTICS

- The model-aerosol consists of modes, each characterized by
  - Homogeneous chemical composition
  - Log-normal size distribution

$$n(r)dr = \frac{N}{\sqrt{2\pi}\sigma_g} \exp\left[\frac{-(\ln r - \ln r_g)^2}{2\sigma_g^2}\right] d\ln r$$

The defining parameters of the log-normal form are

N = Total Particle Number Concentration

r_g = Geometric Mean Radius (by number)

σ_g = Geometric Standard Deviation

- Why the log-normal form ?
  - Representative for ambient aerosols
  - Convenient analytical and numerical properties

- Assume that the evolution of the particle size distribution can be described (approximately) by the evolution of the free defining parameters of the corresponding log-normal modes.

- Solve prognostic equations for an adequate number of moments of the log-normal modes. The moment of order j is defined by

$$\int r^j n(r) dr$$

Make use of the analytical relation

$$\int r^j n(r) dr = N r_g^j \exp\left(\frac{j^2}{2} \sigma_g^2\right)$$

to obtain N, r_g, σ_g.

  - For nuclear smoke assume a fixed $\sigma_g = 0.3$; free parameters are N and r_g. Solve an equation for the two moments

    $N = \int n(r) dr$ Total number concentration

    $V = \frac{4}{3}\pi \int r^3 n(r) dr$ Total volume

  - For nuclear dust assume a fixed $\sigma_g = 0.7$ and a fixed $r_g = 0.25\ \mu m$. There is only one free parameter, thus solve only an equation for V.

- This method requires integrations over the size distribution of size-dependent terms.
  - The integration is performed analytically if the term can be expressed as a polynomial in the particle radius r.
  - Otherwise the integration is performed via a computationally efficient technique that makes use of a moving "Hermite-quadrature grid" centered around r_g.

- The following processes are included in the model:
  - Sources (different scenarios)
  - 3D Transport (CCM $\longrightarrow$ large scale advection, subgrid scale eddy diffusion)
  - Coagulation
  - Sedimentation
  - Dry Deposition
  - Wet Removal

- The prognostic equation for the moments of the particle modes has the form

$$\frac{\partial N,V}{\partial t} = \left[\frac{\partial N,V}{\partial t}\right]_{sourc} + \left[\frac{\partial N,V}{\partial t}\right]_{transp} + \left[\frac{\partial N,V}{\partial t}\right]_{coag} + \left[\frac{\partial N,V}{\partial t}\right]_{sedim} + \left[\frac{\partial N,V}{\partial t}\right]_{drydep} + \left[\frac{\partial N,V}{\partial t}\right]_{wetrem}$$

COAGULATION

- At the present stage this term includes only intramodal Brownian Coagulation

$$\left[\frac{\partial N}{\partial t}\right]_{coag} = -\frac{1}{2}K_N N^2$$

$$\left[\frac{\partial V}{\partial t}\right]_{coag} = 0$$

.where

$$K_N = \int\int \frac{K(r,s)}{2\pi\sigma_g^2} \exp\left(-\frac{(\ln r - \ln r_g)^2}{2\sigma_g^2}\right) \exp\left(-\frac{(\ln s - \ln r_g)^2}{2\sigma_g^2}\right) drds$$

and $K(r,s)$ is the Brownian Coagulation kernel.

SEDIMENTATION

- This term is included as the vertical divergence of the gravitational settling flux.

$$\left[\frac{\partial N, V}{\partial t}\right]_{sedim} = \frac{\partial I_{N,V}}{\partial z}$$

where $I_{N,V}$ are the integrated particle gravitational settling fluxes

$$I_N = \int v_g(r)n(r)dr$$

$$I_V = \frac{4}{3}\pi \int r^3 v_g(r)n(r)dr$$

and v_g is the particle gravitational settling velocity.

- The vertical derivatives are approximated via a mass conserving finite difference scheme.

DRY DEPOSITION

- The dry deposition term is calculated at the bottom model level as

$$\left[\frac{\partial N, V}{\partial t}\right]_{drydep} \propto -D_{N,V}$$

where $D_{N,V}$ are the integrated particle dry deposition fluxes

$$D_N = \int v_d(r) n(r) dr$$

$$D_V = \frac{4}{3}\pi \int r^3 v_d(r) n(r) dr$$

and v_d is the particle deposition velocity.

- The particle deposition velocity is parameterized in terms of:
  - Surface momentum drag coefficient
  - Wind speed, air density, and temperature at the bottom CCM level
  - Particle radius and density
  - Characteristics of the surface roughness elements

- Deposition processes included in the parameterization are:
  - Turbulent transport through the Boundary Layer
  - Brownian Diffusion, Interception, and Impaction on the surface roughness elements

- Surface types considered are
  - Land (treated as a grassy surface)
  - Ocean
  - Snow and Sea Ice

WET REMOVAL

- The model includes only in-cloud scavenging.

- The assumption is made that the aerosol is hygroscopic and that inside clouds at the onset of precipition it resides entirely in the liquid phase. The local particle removal rate is thus equal to the liquid water removal rate λ (s^{-1}), i.e.

$$\left[\frac{\partial N, V}{\partial t}\right]_{wetrem} = -\lambda [N, V]$$

(Note that this term does not affect the value of r_g).

- λ is calculated in terms of the local CCM-produced condensation rate Q as follows:
  - Since precipitation is a sub-grid process the following quantities are first defined:

    F = fraction of the grid box where precipitation occurs

    β = in-cloud liquid water removal rate

    L = in-cloud liquid water content

    T_b = duration of the precipitation event within the time step Δt.

$$Q = FL\beta \frac{T_b}{\Delta t}$$

  - At each grid point and time step λ is given by

$$\lambda = \frac{-F}{\Delta t}\left[e^{-\beta T_b} - 1\right]$$

  - F, β, L, T_b are expressed in terms of Q and/or given parameters. Different parameterizations are used for stable and unstable condensation.

- Validation of wet removal parameterization.

  - CCM-derived TROPOSPHERIC RESIDENCE TIMES (τ) of transparent aerosols with different source distributions:

    Surface injection $\longrightarrow \tau$ = 2-3 days

    Lower tropospheric injection ($z \leq 7$ km) $\longrightarrow$

    τ = 5-7 days

    Middle tropospheric injection ($4 \leq z \leq 10$ km) $\longrightarrow$

    τ = 10-15 days

    Stratospheric injection $\longrightarrow \tau$ = 25-35 days

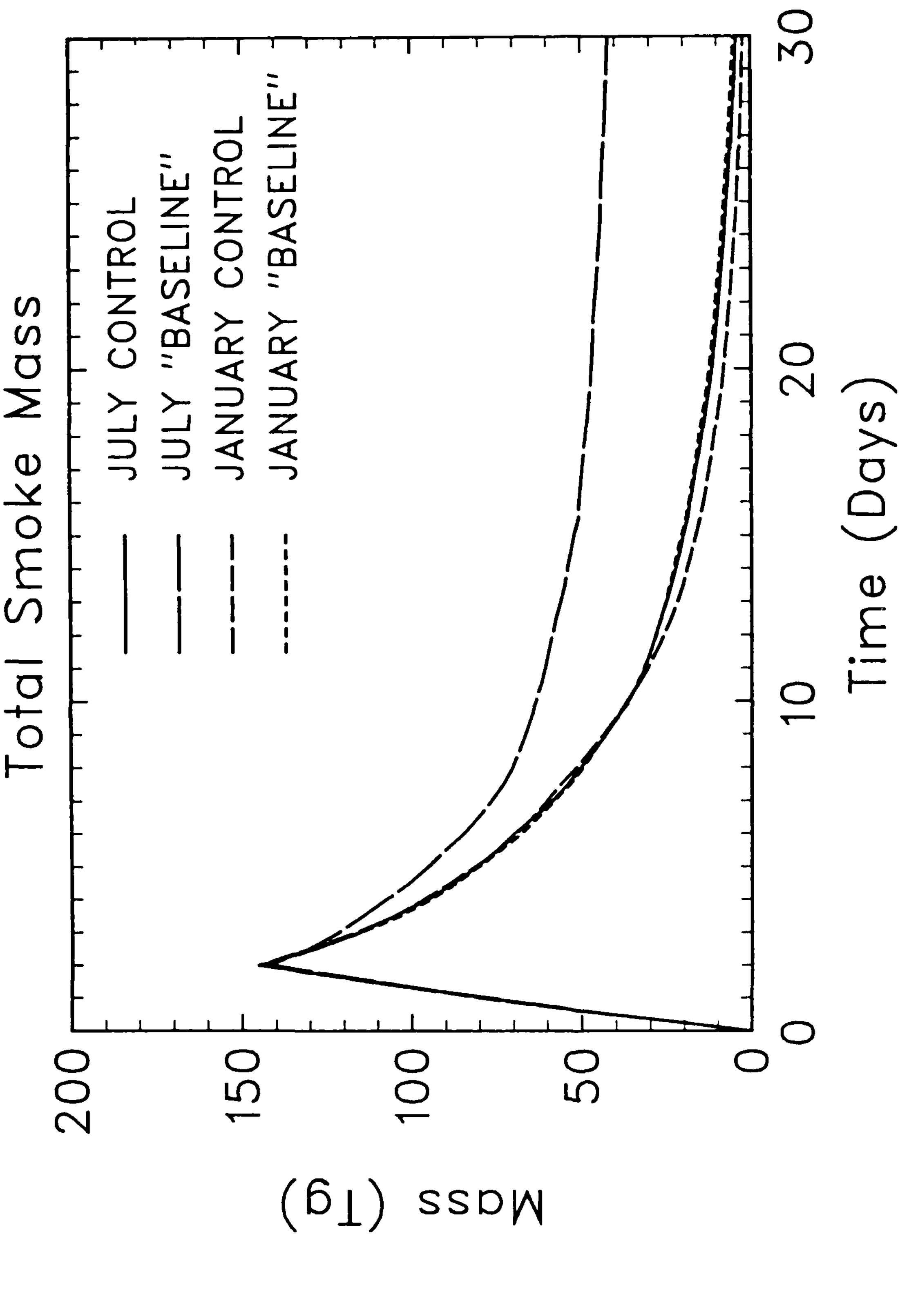
  - Generally good agreement is found with available estimates from atmospheric radionuclide observations.

EFFECTS OF MICROPHYSICS IN INTERACTIVE NUCLEAR WINTER SIMULATIONS

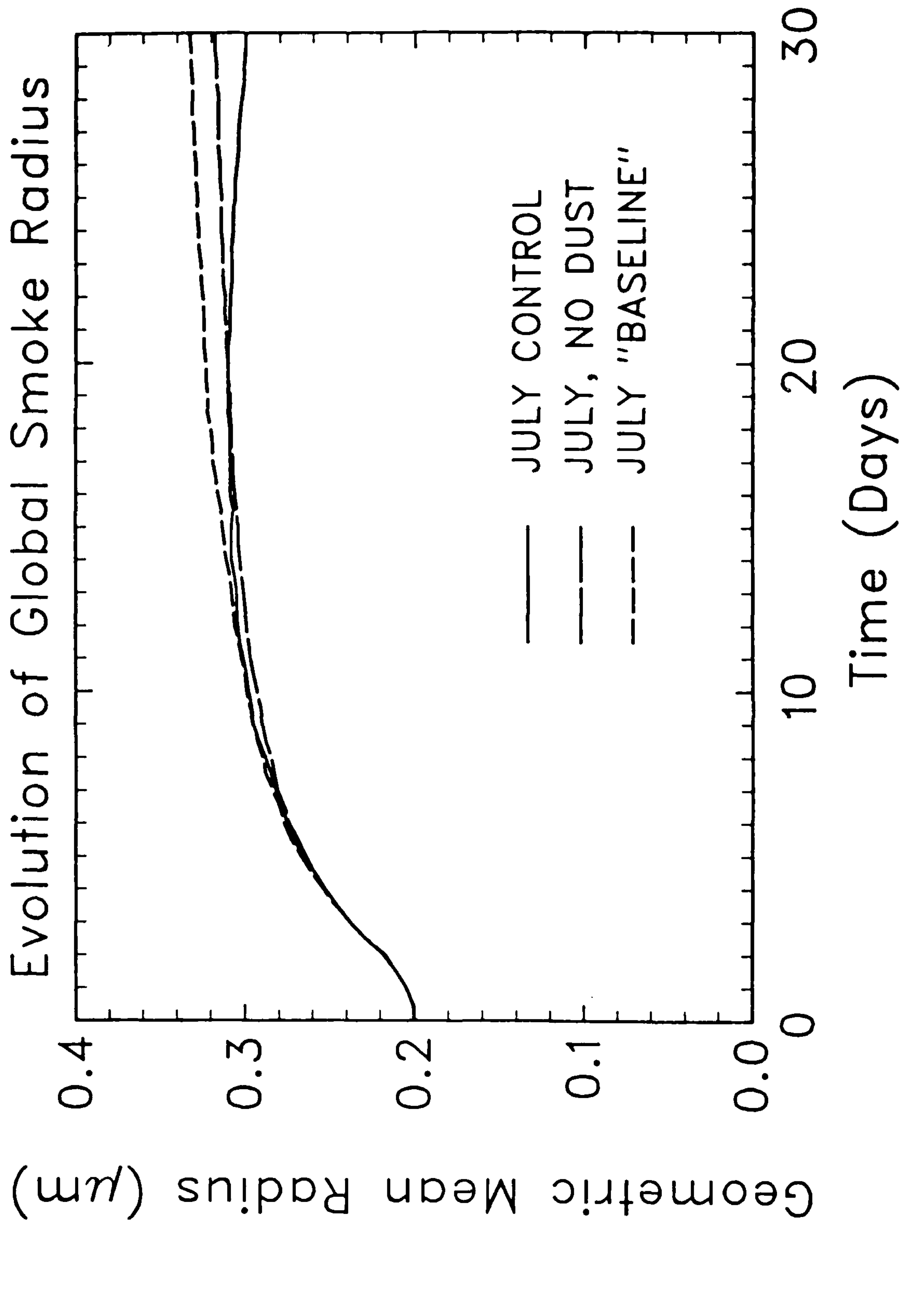
- Sedimentation and Dry Deposition
  - No major effects in 30-day simulations.
  - Possibly more important on a longer time scale or for hydrophobic aerosols.

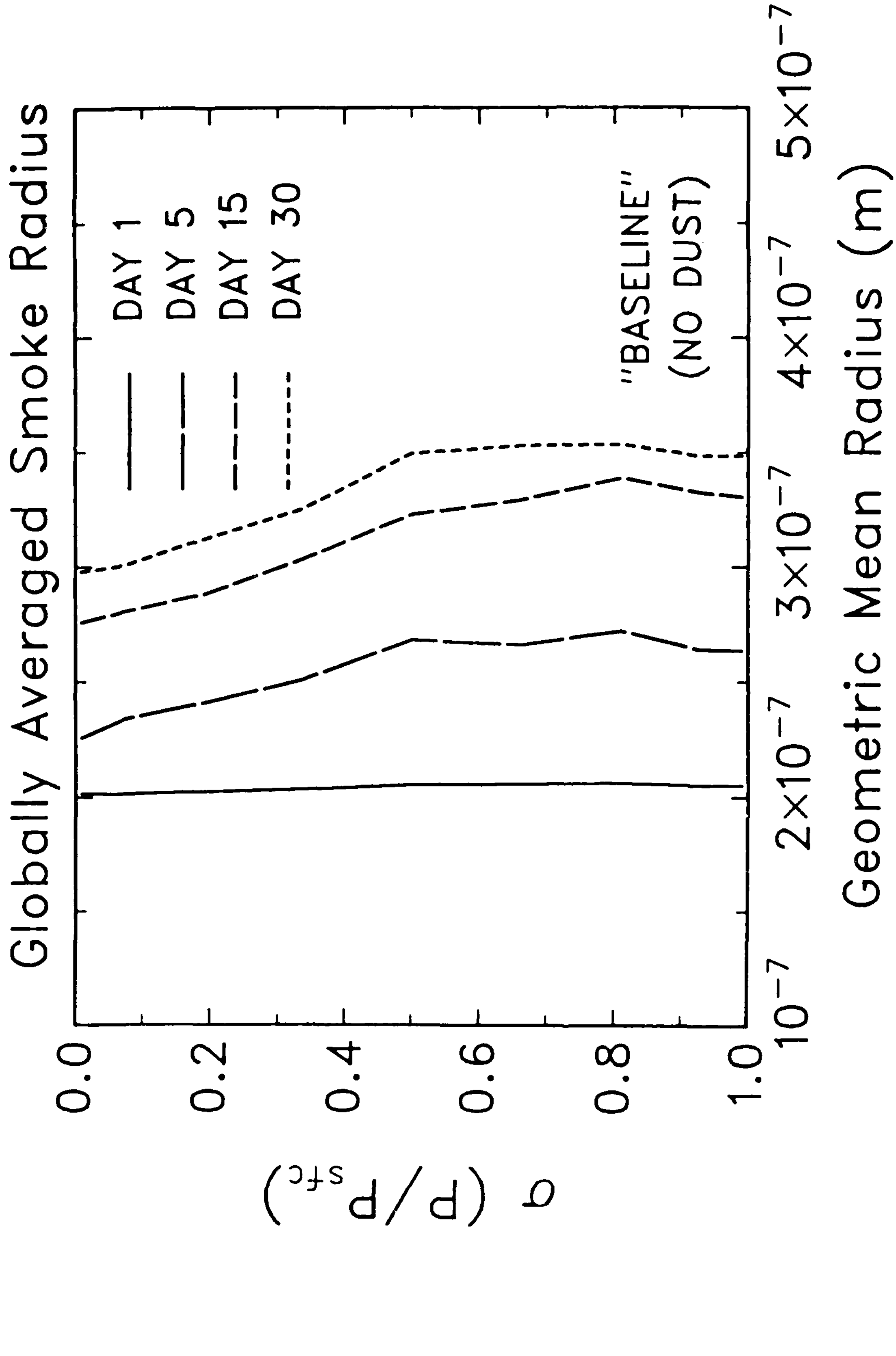
- Wet Removal
  - Very important because it determines smoke atmospheric residence times.
  - The smoke residence time increases from a value of the order of a few days for the case of transparent aerosols to a value of the order of 100 days when the radiative effects of smoke have altered the thermal and dynamical structure of the atmosphere.

- Coagulation
  - Of relevance because it affects the value of the smoke geometric mean radius and, in turn, the smoke bulk optical properties.



Total Smoke Mass
JULY CONTROL
JULY "BASELINE"
JANUARY CONTROL
JANUARY "BASELINE"
Mass (Tg)
Time (Days)
200
150
100
50
0
0
10
20
30


Evolution of Global Smoke Radius
Geometric Mean Radius (μm)
0.0
0.1
0.2
0.3
0.4
0
10
20
30
Time (Days)
JULY CONTROL
JULY, NO DUST
JULY "BASELINE"



Globally Averaged Smoke Radius
DAY 1
DAY 5
DAY 15
DAY 30
"BASELINE"
(NO DUST)
σ (P/P_sfc)
0.0
0.2
0.4
0.6
0.8
1.0
10^-7
2×10^-7
3×10^-7
4×10^-7
5×10^-7
Geometric Mean Radius (m)

Changes in Atmospheric Trace Gas Composition Resulting from Nuclear Exchange: Modification of Atmospheric Chemical Properties and Climate Affect

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Nien Dak Sze,[1] Charles G. Kolb,[2]
and Michael B. McElroy[3]

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[2]Aerodyne Research Incorporated, Billerica, MA

[3]Harvard University, Center for Earth and Planetary Physics, Cambridge, MA

OUTLINE

Photochemical and Climatic Effects of Trace Gases Injections

- Previous studies

- Estimated inputs compared with current global burdens and fluxes

- Effects

Direct	Climate
Indirect	O_3, tropospheric OH climate, chronic biological impact, military operations

- Interactions--relations to other areas

Previous Studies (Pre-1980)

Effect of NO_x on O_3

Effects of oxides of nitrogen on stratospheric O_3

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$NO_2 + O \rightarrow NO + O_2$$

$$O + O_3 \rightarrow 2\ O_2$$

Addition of NO_x leads to reduction of O_3 in the stratosphere

Tropospheric ozone

$$ROO + NO \rightarrow NO_2 + RO$$

$$NO_2 + h\nu \rightarrow NO + O$$

$$O + O_2 \xrightarrow{M} O_3$$

higher NO_x => higher O_3 production

Net effect of NO_x injections depend on amount and altitude distributions and ROO.

Trace Gas Inputs

Species	Input	Global Burden	Impact
Oxides of Nitrogen			
Fireball	12 MT(N)	1 MT(N) (stratosphere)	doubling from 20 ppbv to 40 ppbv
Fires	24 MT(N)		
N_2O	12 MT(N)	10^3 MT	small, few percent increase
CO	2×10^3 MT	380 MT	4-5 time increase
CH_4	10^3 MT	5×10^3 MT	20 percent increase
Hydrocarbon (C_2H_6)	10^3 MT	(8 MT)	large increase
Water	8×10^2 MT	1500 MT	50 percent increase

Trace Gas Inputs

Species	Input	Estimated Flux	Lifetime	Impact
Oxides of Nitrogen				
Fireball	12 MT(N)	Stratosphere 0.5 MT(N)/yr	~ 1 year	~ few years
Fires	24 MT(N)	Troposphere 50 MT(N)/yr	~ days	~ days
N_2O	12 MT(N)	10 MT(N)/yr	150 years	~ 100 years
CO	2×10^3 MT	10^3 MT/yr	100 days	few years
CH_4	10^3 MT	320 MT/yr	10 years	~ 10 years
Hydrocarbon (C_2H_6)	10^3 MT	35 MT/yr	100 days	few years
Water	8×10^2 MT	From CH_4 oxidation 360 MT/yr.	few years	few years

Direct Effect

NO_2 — Solar Heating

$$\left.\begin{array}{l} N_2O \\ H_2O \\ \text{Hydrocarbon, } CH_4 \\ HNO_3 \end{array}\right\} \text{Greenhouse Effect}$$

Dust and Smoke

Obscuration

Indirect Effect

$NO_2 \rightarrow HNO_3$

$CH_4 \rightarrow H_2O$

CO, CH_4 → suppress OH

Dust and smoke → heterogeneous chemistry

<u>ALL AFFECT O_3</u>

Climate

Addition of greenhouse gases

Redistribution of O_3

Photochemical

Stratosphere

O_3

Troposphere

OH, hydrocarbons, O_3

Ozone Chemistry

Production

Photolysis of O_2	Smog Chemistry
$O_2 + h\nu \rightarrow O + O$	$ROO + NO \rightarrow NO_2 + RO$
	$NO_2 + h\nu \rightarrow O + NO$
$O + O_2 \xrightarrow{M} O_3$	$O + O_2 \xrightarrow{M} O_3$

Removal

Oxygen	$O + O_3$
HO_x	$OH + O$; $O + HO_2$
	$OH + O_3$; $O_3 + HO_2$
NO_x	$NO + O_3 \rightarrow NO_2 + O_2$
	$NO_2 + O \rightarrow NO + O_2$
ClO_x	$Cl + O_3 \rightarrow ClO + O_2$
	$ClO + O \rightarrow Cl + O_2$

Things that affect ozone (ppm)

CH_4, H_2O	(ppm)
OH, HO_2	(ppb)
N_2O	(ppb)
NO, NO_2, HNO_3	(ppb)
CFCs	(ppb)
Cl, ClO, HCl	(ppb)

Tropospheric OH

Production

$$O_3 + h\nu \rightarrow O(^1D) + O_2$$

$$O(^1D) + H_2O \rightarrow 2OH$$

Removal

$$OH + CH_4$$

$$OH + CO-$$

Role: Cleansing agent in the troposphere controls concentration of gases such as $(CH_3)_2S$, H_2S, hydrocarbons, CH_2Cl.

The lifetimes of some of these gases is ~ days

If production of these gases is maintained while OH is suppressed, the concentrations will increase significantly within days.

No sunlight, no OH

Build up of $(CH_3)_2S$, H_2S, hydrocarbons

OH production resumes after return of sunlight; however, CO, CH_4 concentrations are much higher. OH concentration could be much smaller. Recovery time will take years.

Question: Could enhanced penetration of UV radiation due to removal of stratospheric O_3 and higher tropospheric concentration of O_3 from smog reactions compensate for the increased CO and CH_4?

Ozone and other processes

Heat budget radiation $\leftrightarrow$ circulation

Optical properties of atmosphere

photolysis rates

Chemistry $O(^1D) + H_2O \rightarrow HO_x$

$O(^1D) + N_2O \rightarrow NOY$

Shielding of UV radiation

Smog chemistry

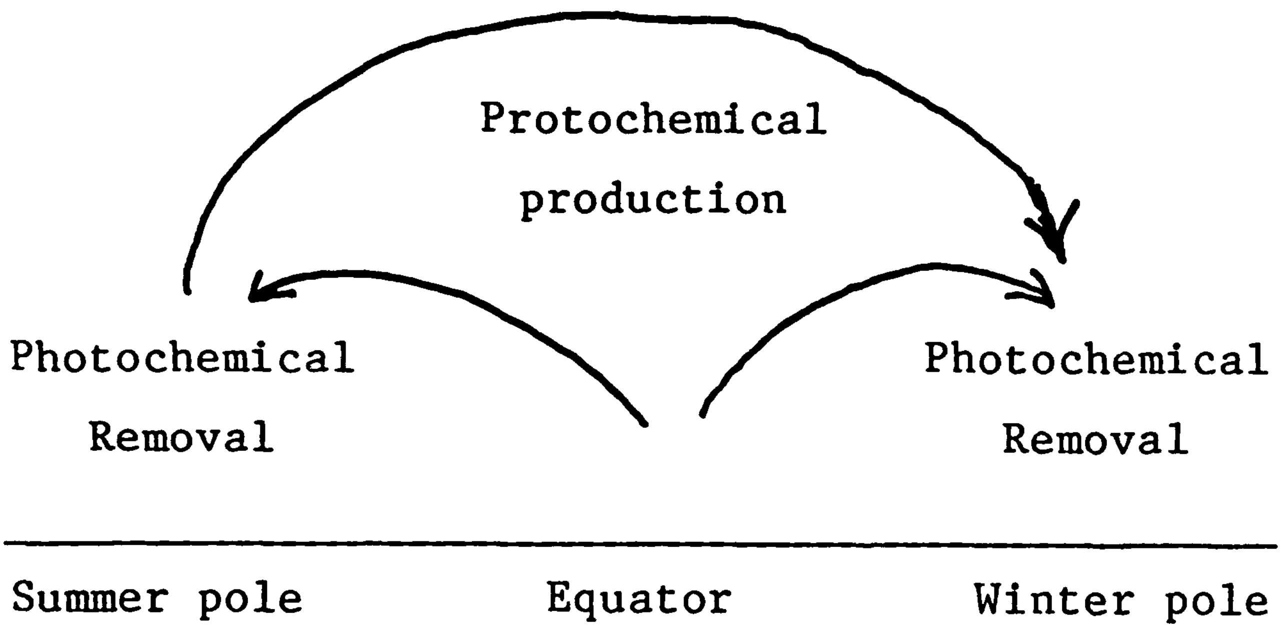
Effect on plants

CHANGE IN O_3

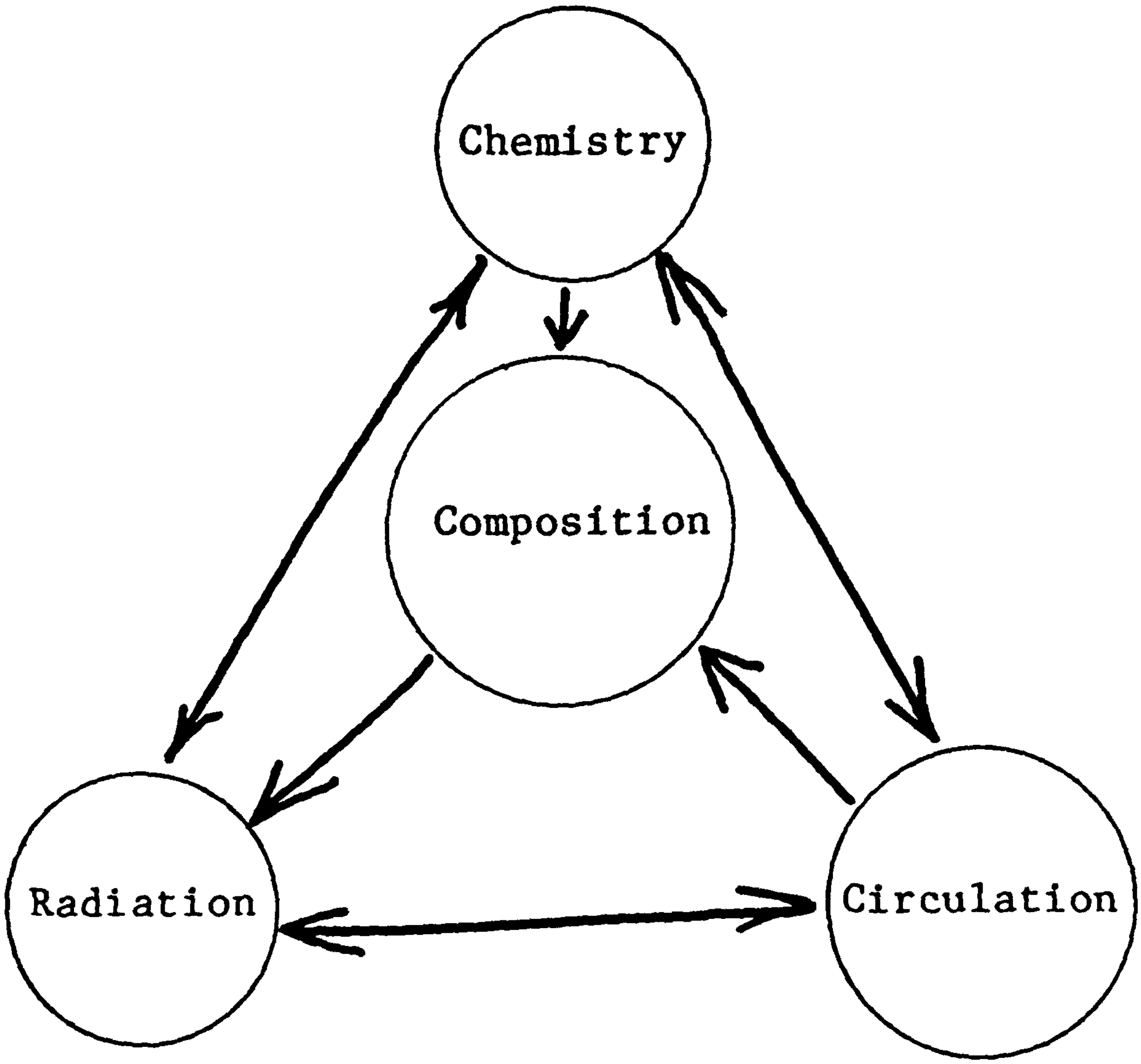
- → change in radiative balance
- → change in transport circulation
- → change in photochemical balance

Effects of Transport on Ozone

Zonal-mean Picture



Change in transport will effect O_3



Interactions

AER MODELS

1-D photochemical-diffusion model

1-D diurnal model

1-D radiative convective photochemical model

2-D zonal-mean model

- diabatic circulation formulation
- classical Eulerian formulation

2-D climate model

3-D semispectral, global primitive equation model

Conclusion

- Atmospheric radiation, dynamics, and chemistry are highly coupled

- Identify areas of interest using simple models

- Solutions of problems through coupled models

DIRTY SNOW EFFECTS ARE OF SMALL CLIMATIC CONSEQUENCE IN NUCLEAR WINTER SCENARIOS

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Paper presented at DNA Global Effects Program Technical Meeting, NASA Ames, 25 February 1986

ABSTRACT

In a nuclear winter scenario, smoke and soot fall out of the atmosphere and lower the albedo of the snow and ice. We use an energy balance climate model to test the effect this would have on moderating the nuclear winter cooling. We find that the effect is small, since the maximum effect on surface albedo occurs when the atmosphere still contains a large amount of soot, thereby reducing the importance of surface albedo.

The climate model illustrates that snow and ice feedbacks can prolong the surface temperature effects of nuclear winter for several years.

TEXT

Following a nuclear war, burning cities would put smoke and soot into the atmosphere. The amount of smoke and its optical properties depend on many factors, as discussed in other papers in this volume. When the smoke is removed from the atmosphere, it will lower the albedo of the snow and ice upon which it falls (Warren and Wiscombe, 1985). In this paper we use several hypothesized nuclear winter scenarios and the albedo effects described by Warren and Wiscombe to calculate, using an energy balance climate model, the effects of dirty snow on moderating the cooling. The figure captions discuss the results in detail. In this text, the experiments we performed are briefly described. A longer paper describing the research in detail is in preparation.

The climate model of Robock (1983, 1984) was used for these experiments. We modified the results of Warren and Wiscombe (1985) to give clean snow and ice albedos to correspond to the values used in the model's surface albedo parameterization (Fig. 1).

Baseline nuclear winter scenarios from Turco, et al. (1983) (TTAPS), National Academy of Sciences (1985) (NAS), and Malone, et al. (1986) were used to force the climate model. The atmospheric smoke mass loading in each of these cases is 225 Tg

(TTAPS), 180 Tg (NAS) and 170 Tg (Malone, et al.). A radiative equilibrium smoke cloud model calculated the downward shortwave and longwave radiation from the cloud as a function of optical depth at each latitude (Crutzen, et al., 1984). For scattering calculations, the assymetry factor was held constant at 0.7 while the single scattering albedo is varied to produce the same solar insolation as published in the NAS and TTAPS papers. We assumed the infrared optical depth was one tenth the optical depth of the visible radiation and ignored scattering of infrared radiation.

The soot component of the smoke was used to calculate the snow and ice albedos (Warren and Wiscombe, 1985). From the information in the above papers, we calculated the fallout rate of soot onto snow as a function of time and latitude. Dirty snow calculations for the Malone et al. case were not carried out because we could not obtain information about the soot fallout. In order to calculate mass fraction of soot in snow, we assumed a precipitation rate of 1 cm liquid water per month. This is a very low rate for the current climate, but was chosen as a "worst case." Some simulations suggest reductions of precipitation as a result of nuclear winter. GCM calculations of snowfall and soot mass fraction were kindly provided by Steve Ghan (Ghan, et al., 1985). Our values give the same or higher soot mass fractions than theirs and the same or lower precipitation rates. Any smaller mass fractions of soot would give less of an albedo effect. We ignore for now the possible reappearance of soot after melting on ice caps or sea ice, which was suggested by Warren and Wiscombe (1985).

We ran the model for the various nuclear winter scenarios with and without dirty snow, and calculate the differences in the surface temperature response. The largest effects are for the TTAPS scenario, and these results are shown in detail. We also demonstrate the model sensitivity to snow/albedo and sea ice/thermal inertia feedbacks separately.

Dirty snow is found to have small effect on ameliorating the cooling induced by massive soot clouds in the atmosphere. The largest effect is for a soot injection in spring, allowing the atmosphere to be clean enough in summer at high latitudes for the large insolation to interact with the darker snow. Still, in this case, the effect is only about 20% of the total cooling at the most.

REFERENCES

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Ghan, Steven J., MacCracken, Michael C. and John J. Walton, 1985: climatic responses to large summertime injections of smoke into the atmosphere: changes in precipitation and the Hadley circulation. (Lawrence Livermore National Laboratory preprint UCRL-92324), 41 pp.

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Robock, Alan, 1984: Snow and ice feedbacks prolong effects of nuclear winter. Nature, 310, 667-670.

Turco, R. P., Toon, O. B., Ackerman, T. P., Pollack, J. B. and C. Sagan, 1983: Nuclear winter: global consequences of multiple nuclear explosions. Science, 222, 1283-1292.

Warren, Stephen G. and Warren J. Wiscombe, 1985: Dirty snow after nuclear war. Nature, 313, 467-470.

FIGURE CAPTIONS

1. Albedo of snow, sea ice, and old snow and sea ice as a function of soot mass fraction in snow. See Robock (1983) for snow and ice albedo parameterizations and Warren and Wiscombe (1985) for soot effects.

2. Response of model to lowering albedo of snow and ice by 50%. Shown are surface air temperature differences from an unperturbed reference run (°C) for first three years following change (a) and at equilibrium (b) as functions of latitude and time of year. The largest effect is in the summer at high latitudes.

3. Extinction optical depth of smoke as a function of time for the scenarios considered. For TTAPS and NAS, the smoke is spread uniformly throughout the Northern Hemisphere. For the Malone et al. cases, the latitudinal spread is time dependent as given in the paper. For times after the end of the GCM run, the smoke is assumed to not spread any more and to decay exponentially in time at the rate specified in the paper. For comparison, an area weighted average was taken of these optical depths to obtain a Northern Heimspheric average.

4. Albedo of new snow as calculated for the TTAPS and NAS cases. We did not have enough information about soot fallout rates to do this calculation for the Malone et al. case.

5. Surface temperature changes (°C) for the TTAPS summer case for the first 5 years of the response (differences from reference run). High latitude enhancement of the response is evident.

6. Demonstration of the cryosphere feedbacks. a.) Difference in response for a case with no snow and ice feedbacks (fixed areas) and control (with all feedbacks, as shown in Fig. 5). b.) As in a., but with only snow area responding. The summertime enhancement is evident. There is little snow/albedo feedback in winter when the sun is weak. c.) As in a., but with only sea ice area responding. The maximum effect is in the winter at high latitudes, because the changing sea ice changes the thermal inertia affecting the amplitude of the seasonal cycle. This feedback dominates the cryosphere feedback.

7. As in Fig. 5, but for NAS scenario. The response is smaller and does not last as long.

8. As in Fig. 5, but for Malone et al. case. The initial response is smaller than the NAS case (Fig. 6), but is longer lasting because of the longer soot residence time (Fig. 3).

9. For a TTAPS scenario with dirty snow (soot case) starting in winter, the surface temperature response (a), the surface temperature difference between the soot case and control case (b), and the albedo difference (c). The cooling is about 1°C less with dirty snow than without it at high latitudes in the summer (b). The largest albedo changes due to dirty snow are in the winter, but the maximum effect is in the summer, due to both a cleaner atmosphere and greater insolation then.

10. As in Fig. 9, but for spring for 3 years. This case shows the largest dirty snow effect, of more than 2°C the first summer and 1°C the second summer.

11. As in Fig. 9, but for summer for 3 years. The actual cooling is greatest for this case, and the dirty snow effect is smaller. This is because by the time the atmosphere becomes clean enough for surface albedo to matter, it is already fall, and insolation has decreased. The fall case has the smallest actual response (Fig. 15) and dirty snow effect, not shown.

12. A five year run of the TTAPS case with dirty snow for winter.

13. A five year run of the TTAPS case with dirty snow for spring.

14. A five year run of the TTAPS case with dirty snow for summer.

15. A five year run of the TTAPS case with dirty snow for fall.

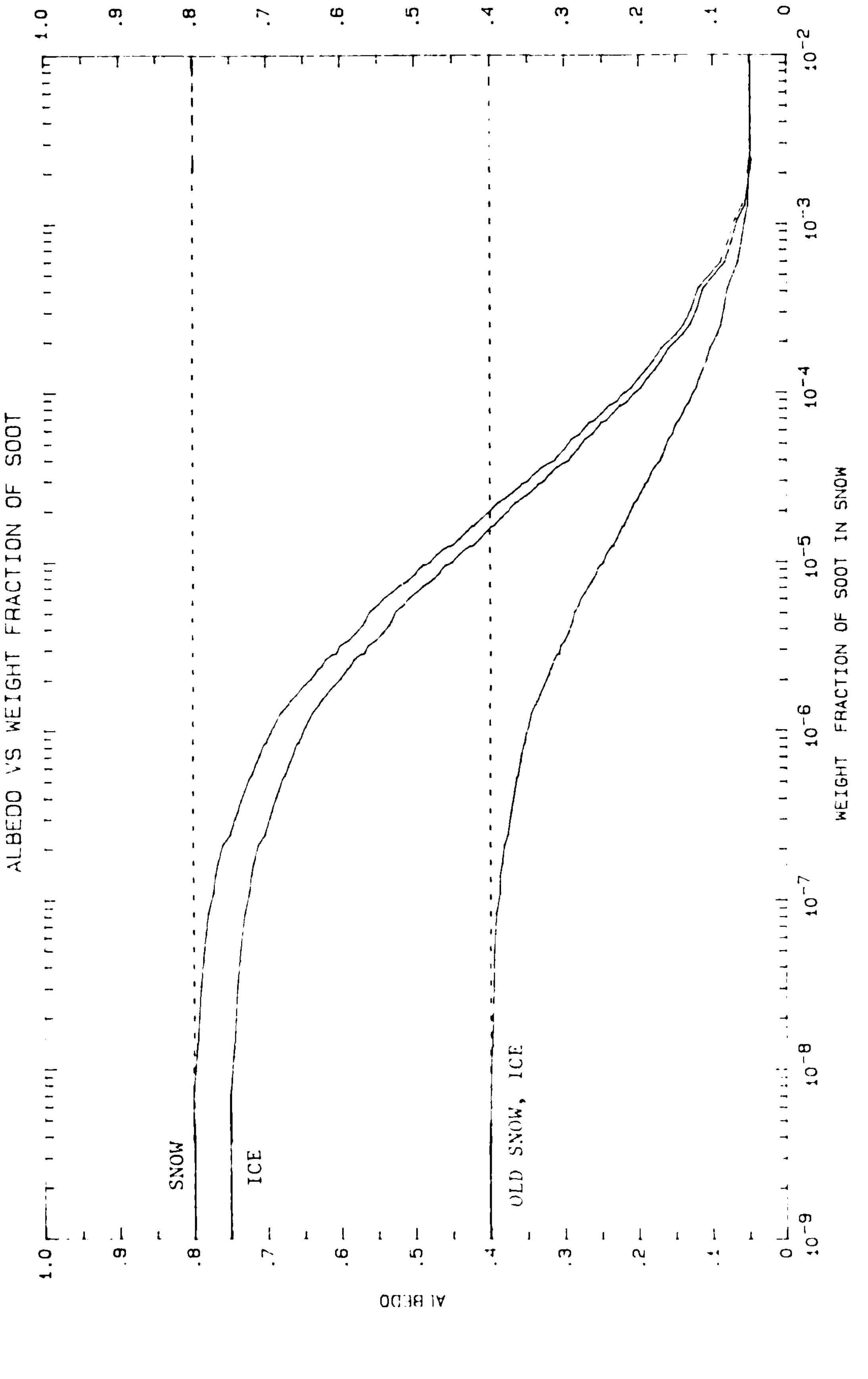
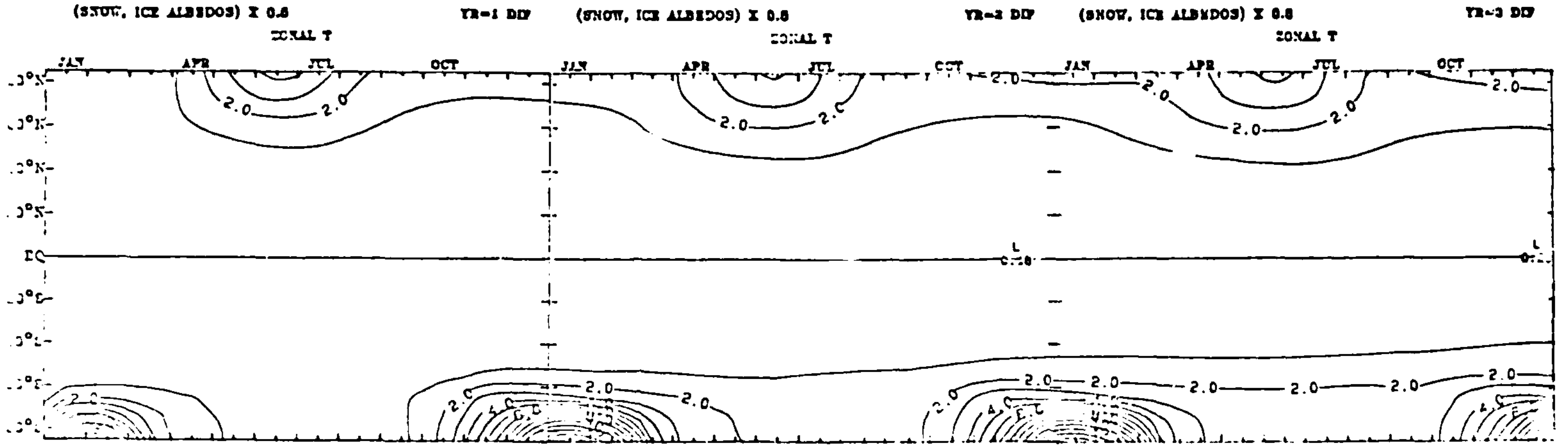

ALBEDO VS WEIGHT FRACTION OF SOOT
SNOW
ICE
OLD SNOW, ICE
WEIGHT FRACTION OF SOOT IN SNOW
ALBEDO
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0

Figure 1

a.


(SNOW, ICE ALBEDOS) X 0.6
ZONAL T
YR=1 DIF
(SNOW, ICE ALBEDOS) X 0.6
ZONAL T
YR=2 DIF
(SNOW, ICE ALBEDOS) X 0.6
ZONAL T
YR=3 DIF
JAN
APR
JUL
OCT
EQ
2.0

b.

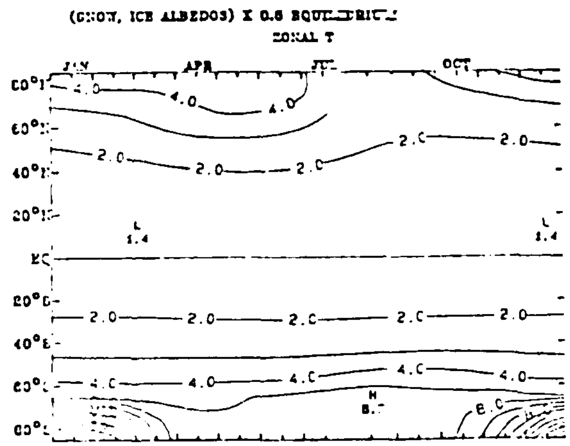
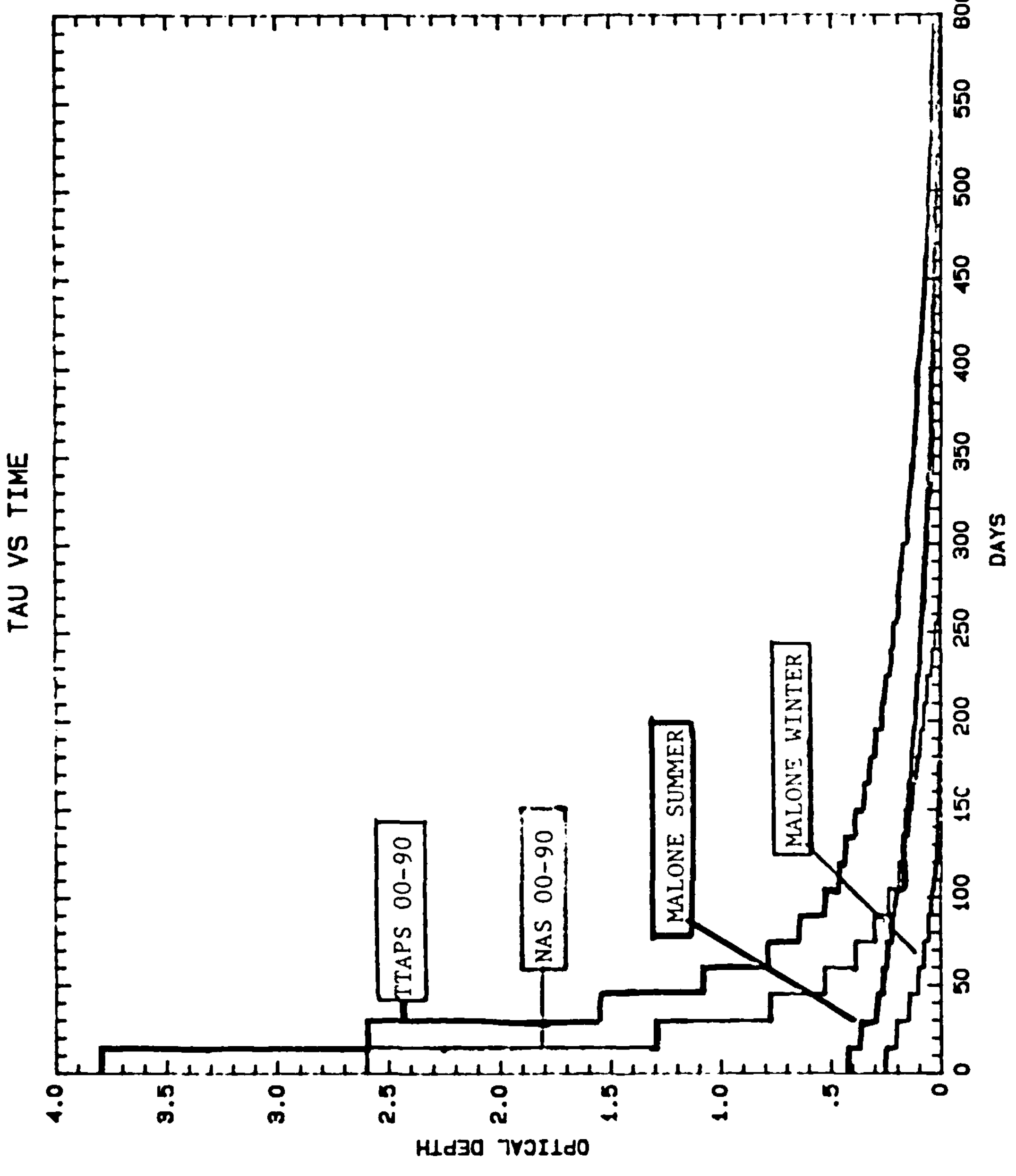

(SNOW, ICE ALBEDOS) X 0.6 EQUILIBRIUM
ZONAL T
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S
2.0
4.0
8.0
L
1.4
H

Figure 2



TAU VS TIME
OPTICAL DEPTH
DAYS
TTAPS 00-90
NAS 00-90
MALONE SUMMER
MALONE WINTER

Figure 3

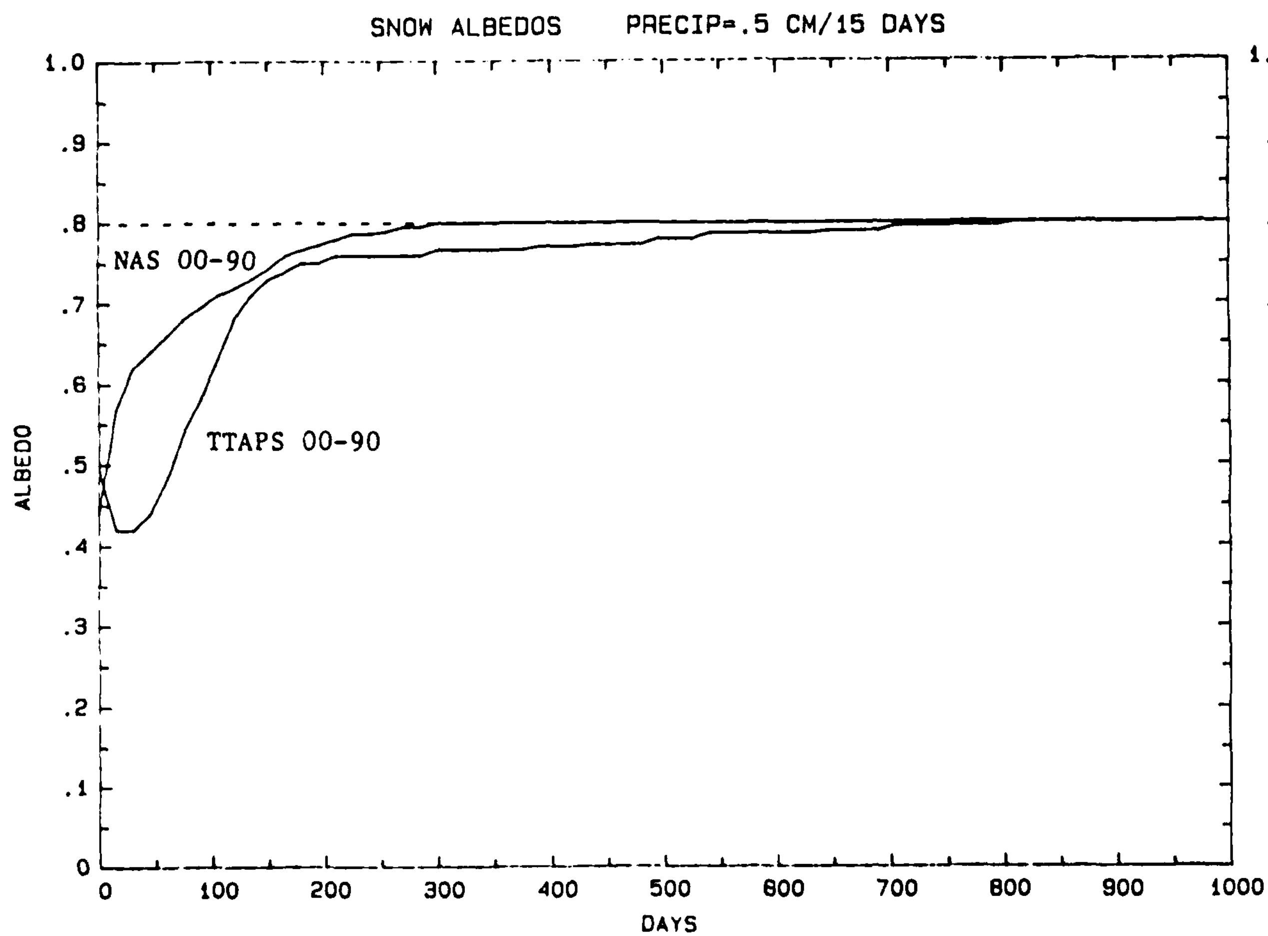

SNOW ALBEDOS PRECIP=.5 CM/15 DAYS
ALBEDO
DAYS
NAS 00-90
TTAPS 00-90
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
100
200
300
400
500
600
700
800
900
1000

Figure 4

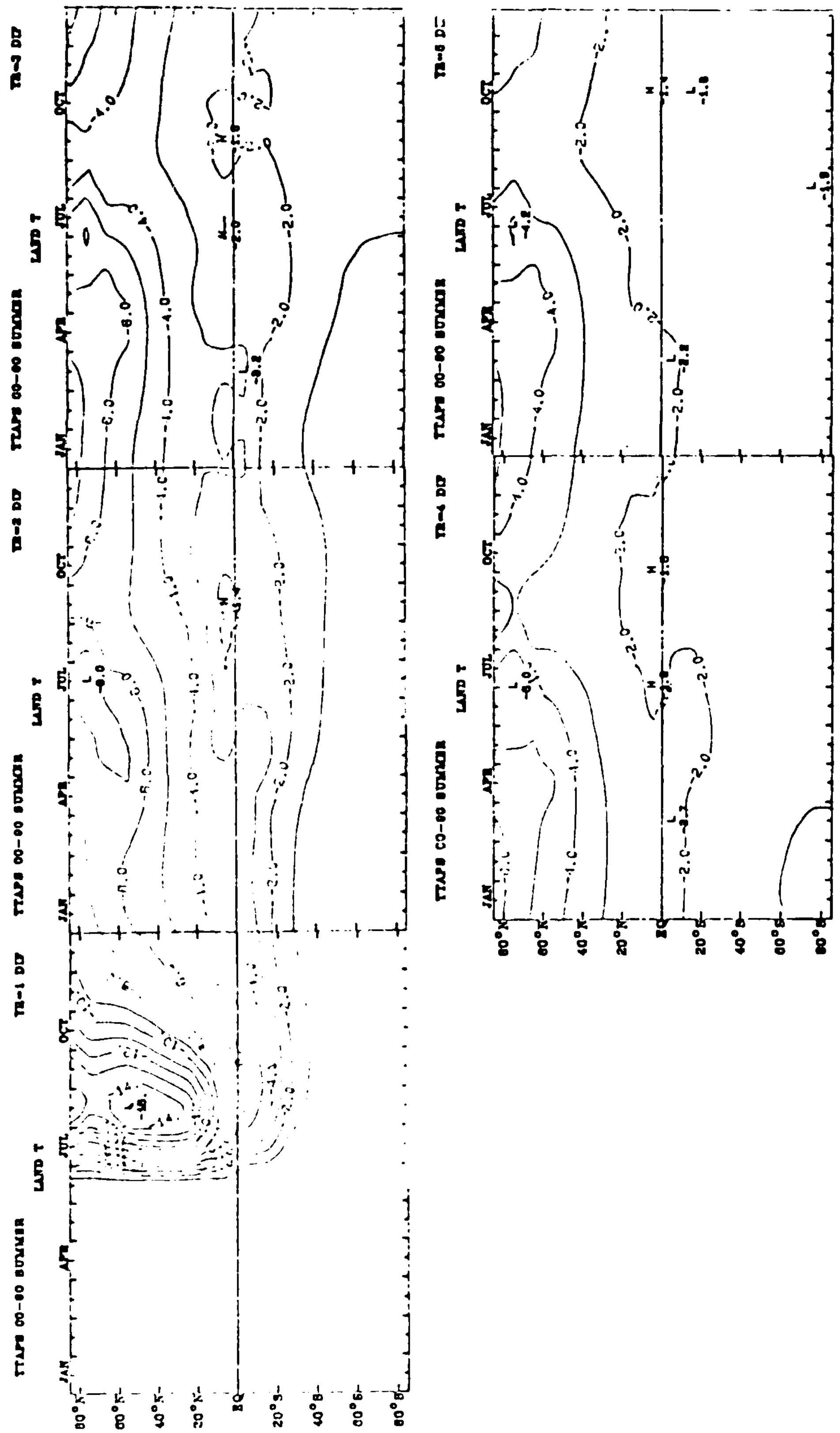
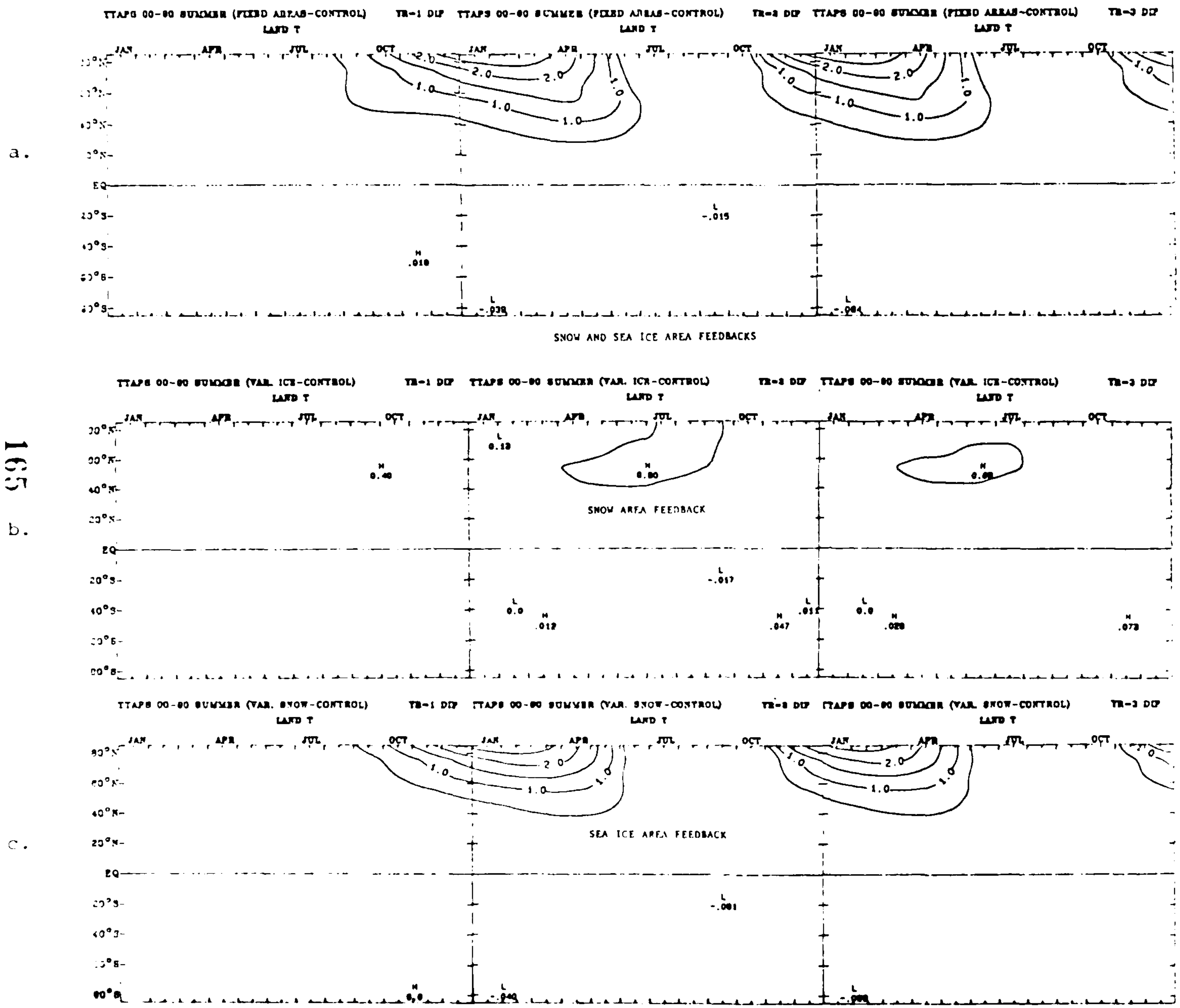


Figure 5

Figure 6


a.
TTAPS 00-90 SUMMER (FIXED AREAS-CONTROL) TR-1 DIF
TTAPS 00-90 SUMMER (FIXED AREAS-CONTROL) TR-2 DIF
TTAPS 00-90 SUMMER (FIXED AREAS-CONTROL) TR-3 DIF
LAND T
SNOW AND SEA ICE AREA FEEDBACKS
b.
TTAPS 00-90 SUMMER (VAR. ICE-CONTROL) TR-1 DIF
TTAPS 00-90 SUMMER (VAR. ICE-CONTROL) TR-2 DIF
TTAPS 00-90 SUMMER (VAR. ICE-CONTROL) TR-3 DIF
LAND T
SNOW AREA FEEDBACK
c.
TTAPS 00-90 SUMMER (VAR. SNOW-CONTROL) TR-1 DIF
TTAPS 00-90 SUMMER (VAR. SNOW-CONTROL) TR-2 DIF
TTAPS 00-90 SUMMER (VAR. SNOW-CONTROL) TR-3 DIF
LAND T
SEA ICE AREA FEEDBACK
JAN
APR
JUL
OCT
EQ

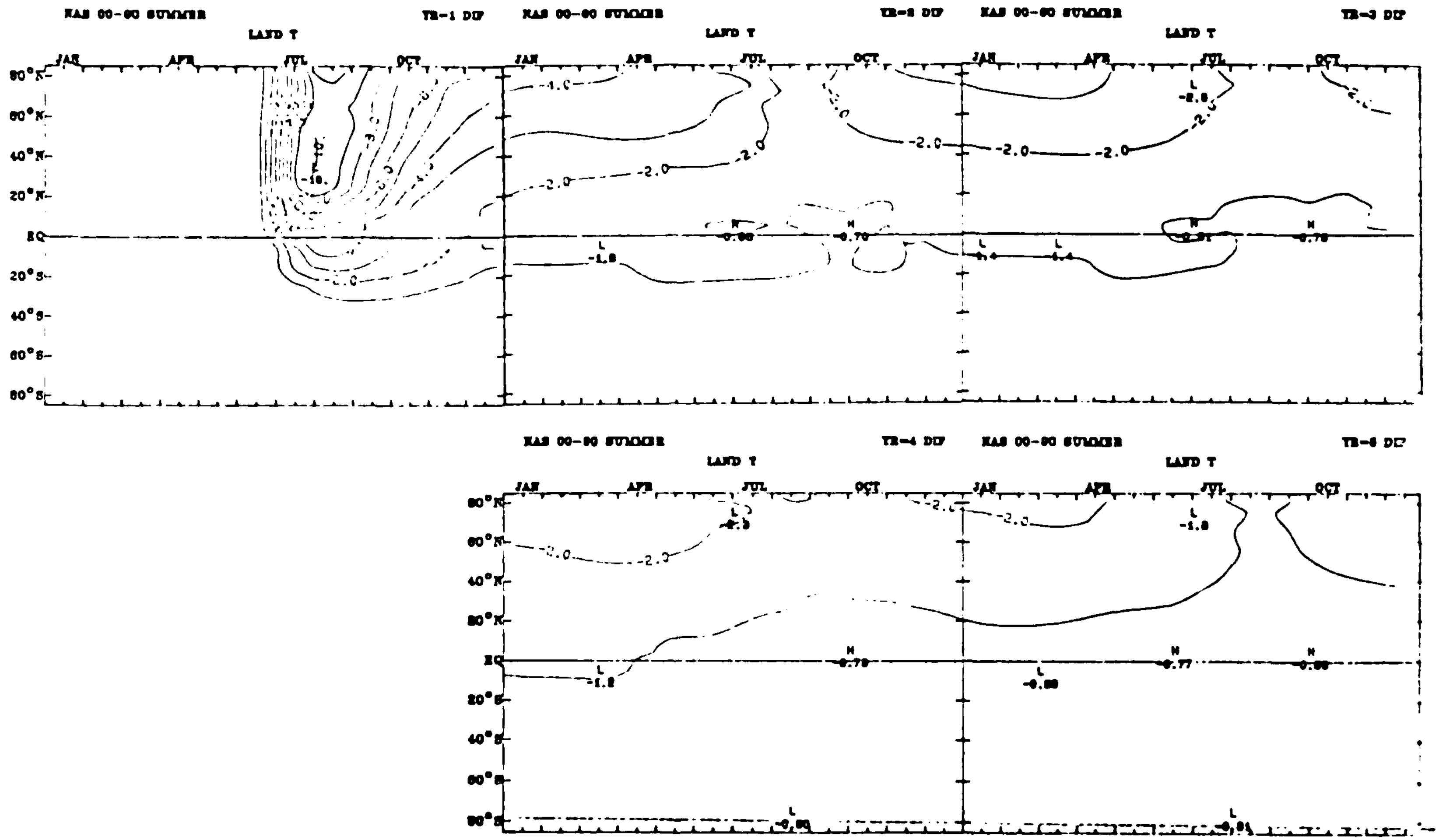
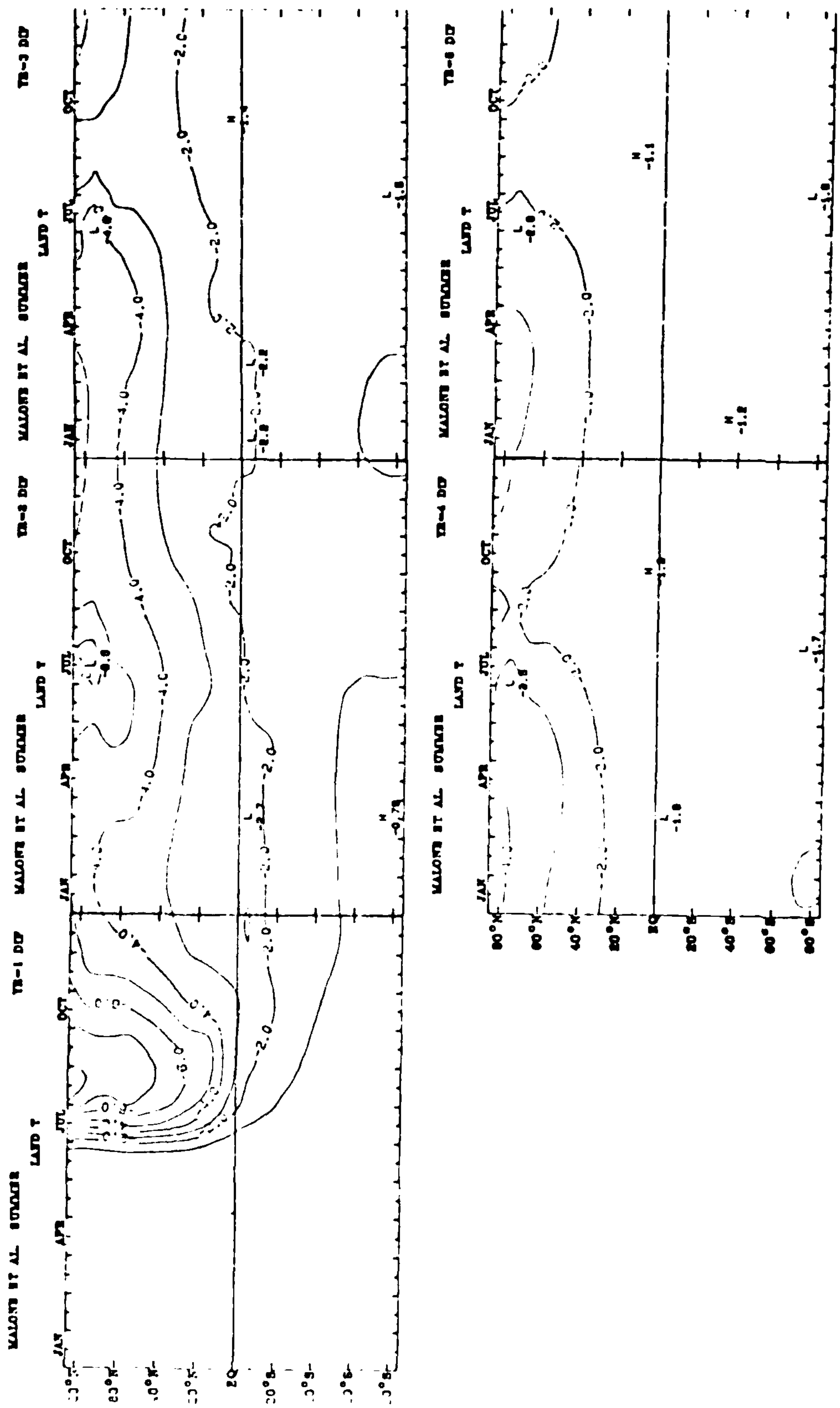


Figure 7



MALONE ET AL. SUMMER
LAND T
TR-1 DIF
TR-2 DIF
TR-3 DIF
TR-4 DIF
TR-5 DIF
JAN
APR
JUL
OCT
EQ

Figure 8

a.

b.

c.

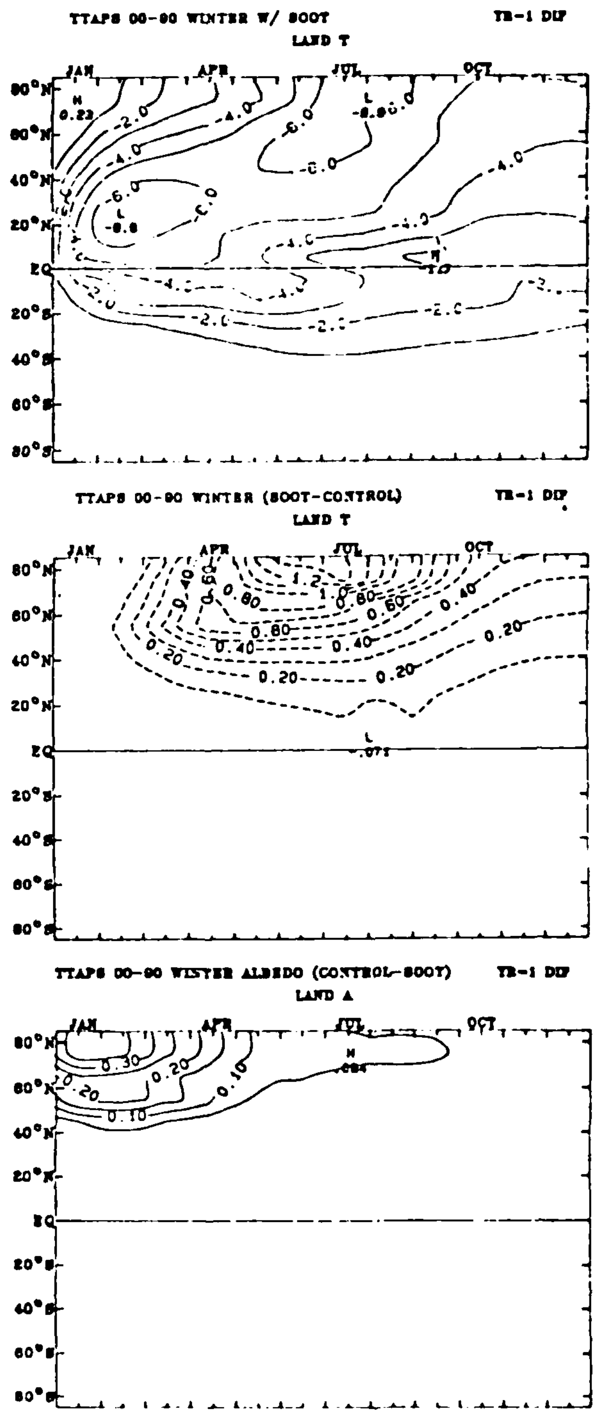

TTAPS 00-90 WINTER W/ SOOT
TR-1 DIF
LAND T
TTAPS 00-90 WINTER (SOOT-CONTROL)
TR-1 DIF
LAND T
TTAPS 00-90 WINTER ALBEDO (CONTROL-SOOT)
TR-1 DIF
LAND A

Figure 9

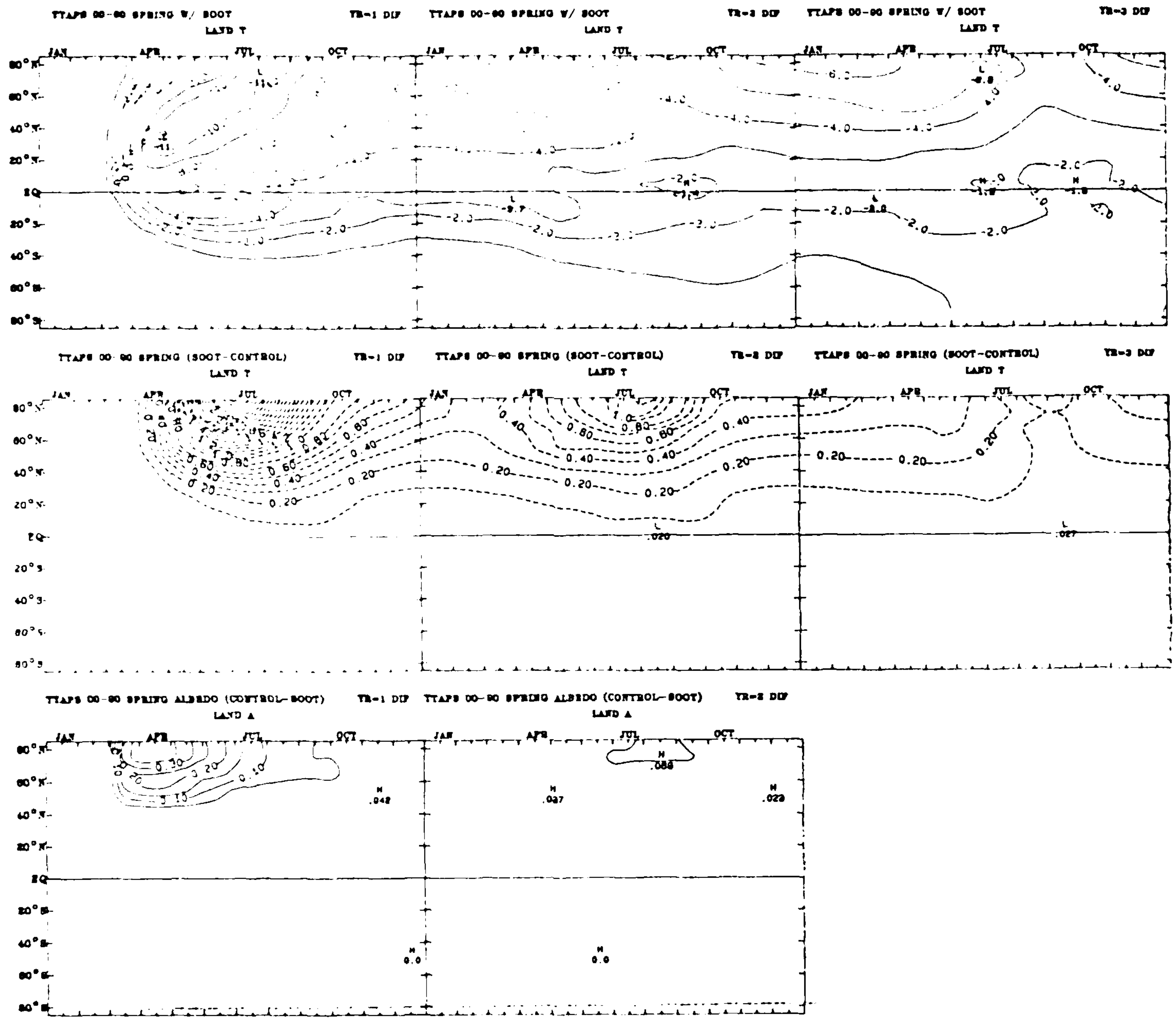

TTAPS 00-90 SPRING W/ SOOT
LAND T
YR=1 DIF
TTAPS 00-90 SPRING W/ SOOT
LAND T
YR=2 DIF
TTAPS 00-90 SPRING W/ SOOT
LAND T
YR=3 DIF
TTAPS 00-90 SPRING (SOOT-CONTROL)
LAND T
YR=1 DIF
TTAPS 00-90 SPRING (SOOT-CONTROL)
LAND T
YR=2 DIF
TTAPS 00-90 SPRING (SOOT-CONTROL)
LAND T
YR=3 DIF
TTAPS 00-90 SPRING ALBEDO (CONTROL-SOOT)
LAND A
YR=1 DIF
TTAPS 00-90 SPRING ALBEDO (CONTROL-SOOT)
LAND A
YR=2 DIF
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S

Figure 10

a.

b.

c.

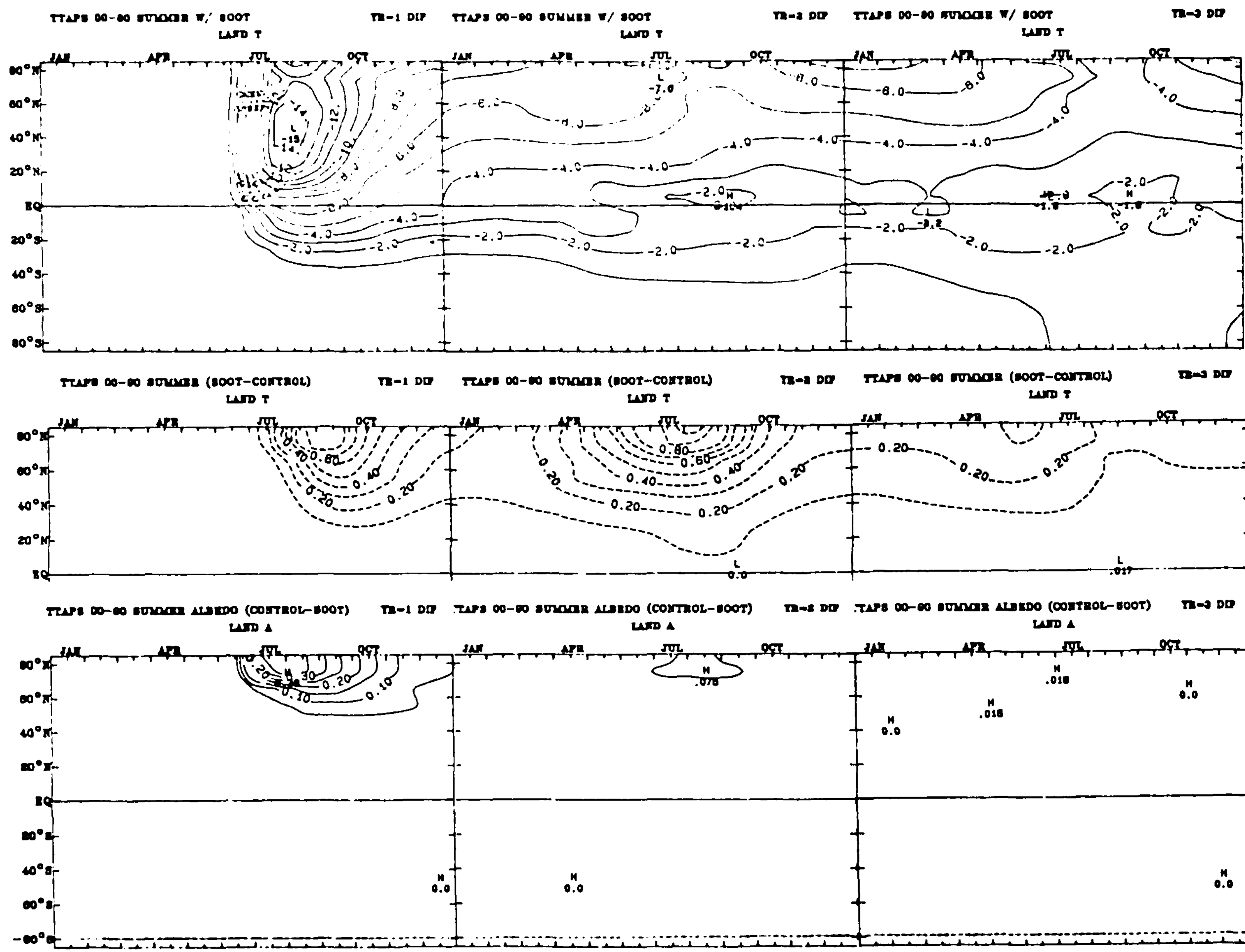


Figure 11

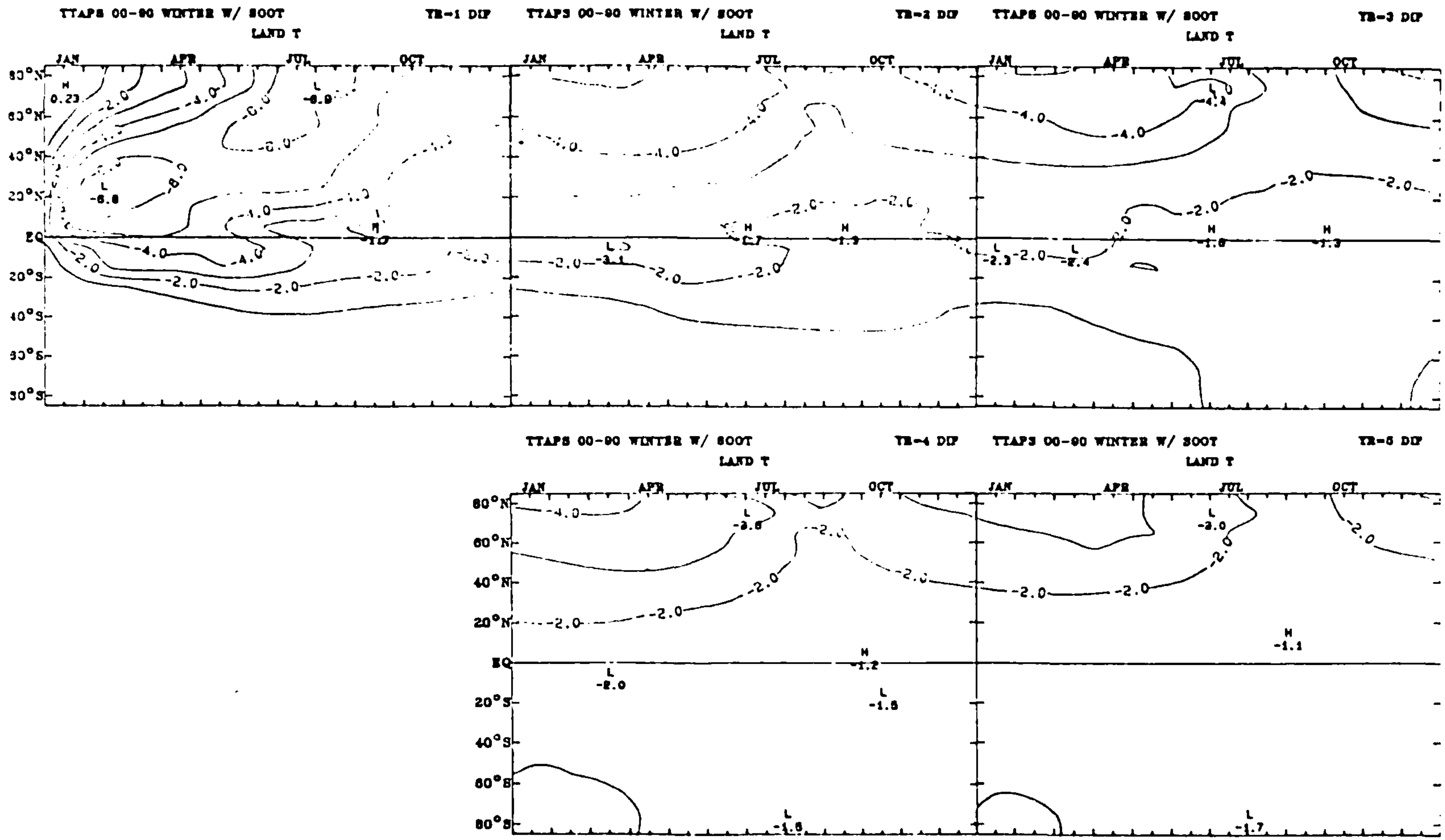

TTAPS 00-90 WINTER W/ SOOT
LAND T
YR-1 DIF
TTAPS 00-90 WINTER W/ SOOT
LAND T
YR-2 DIF
TTAPS 00-90 WINTER W/ SOOT
LAND T
YR-3 DIF
TTAPS 00-90 WINTER W/ SOOT
LAND T
YR-4 DIF
TTAPS 00-90 WINTER W/ SOOT
LAND T
YR-5 DIF
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S

Figure 12

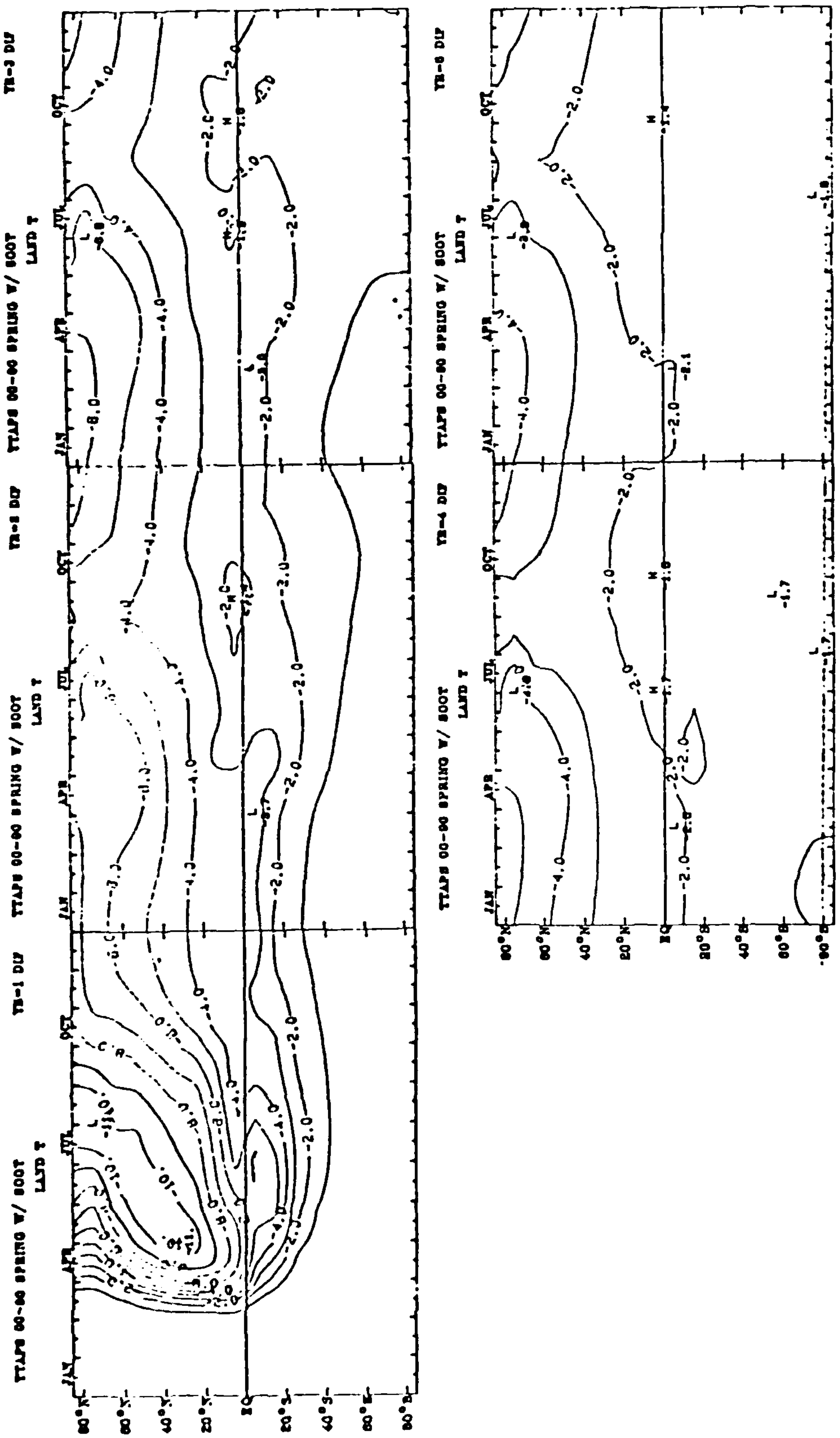

TTAPS 00-90 SPRING W/ SOOT
LAND T
YR-1 DIF
YR-2 DIF
YR-3 DIF
YR-4 DIF
YR-5 DIF
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S

Figure 13

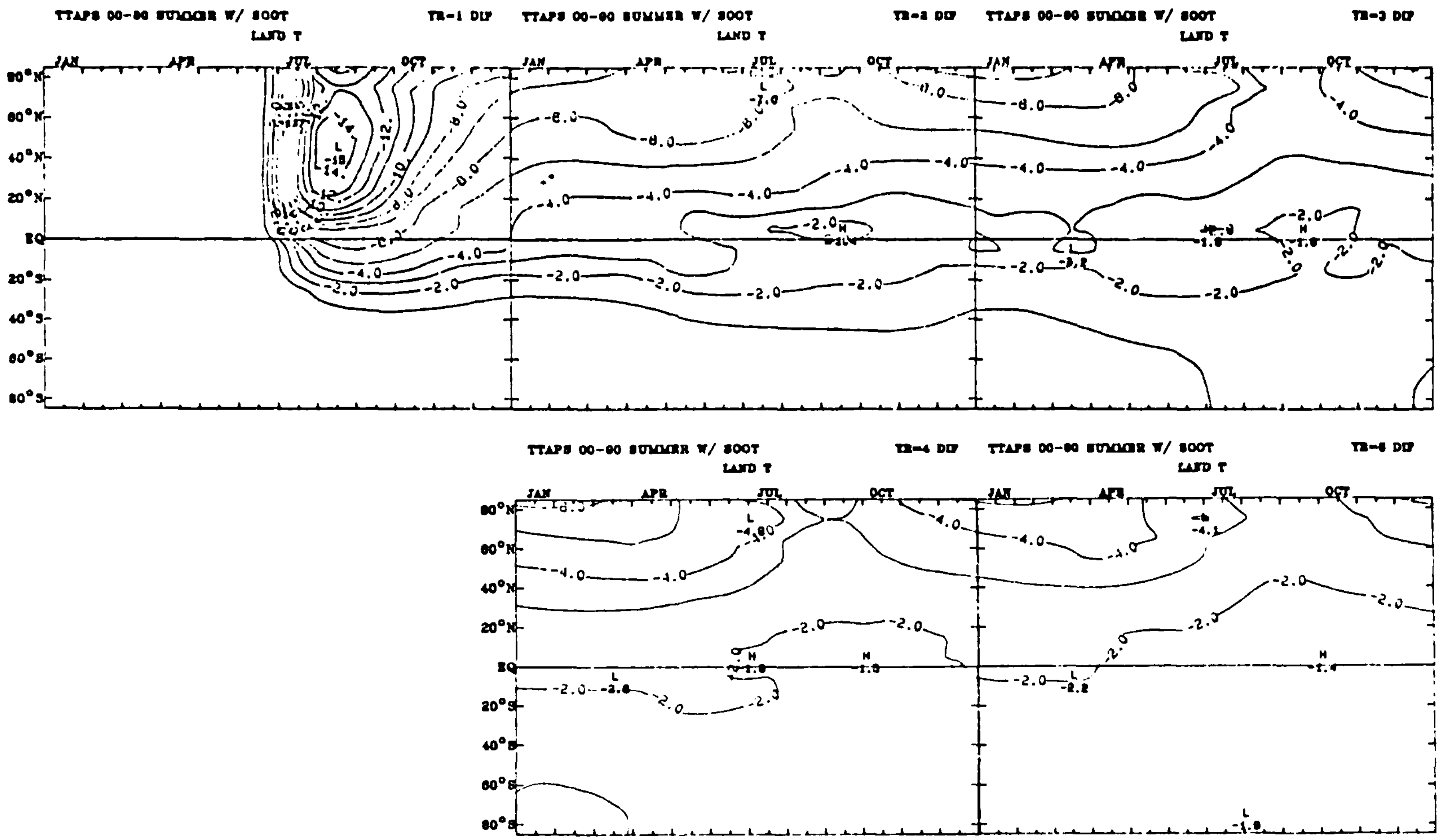

TTAPS 00-90 SUMMER W/ SOOT
LAND T
YR-1 DIF
TTAPS 00-90 SUMMER W/ SOOT
LAND T
YR-2 DIF
TTAPS 00-90 SUMMER W/ SOOT
LAND T
YR-3 DIF
TTAPS 00-90 SUMMER W/ SOOT
LAND T
YR-4 DIF
TTAPS 00-90 SUMMER W/ SOOT
LAND T
YR-5 DIF
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S

Figure 14

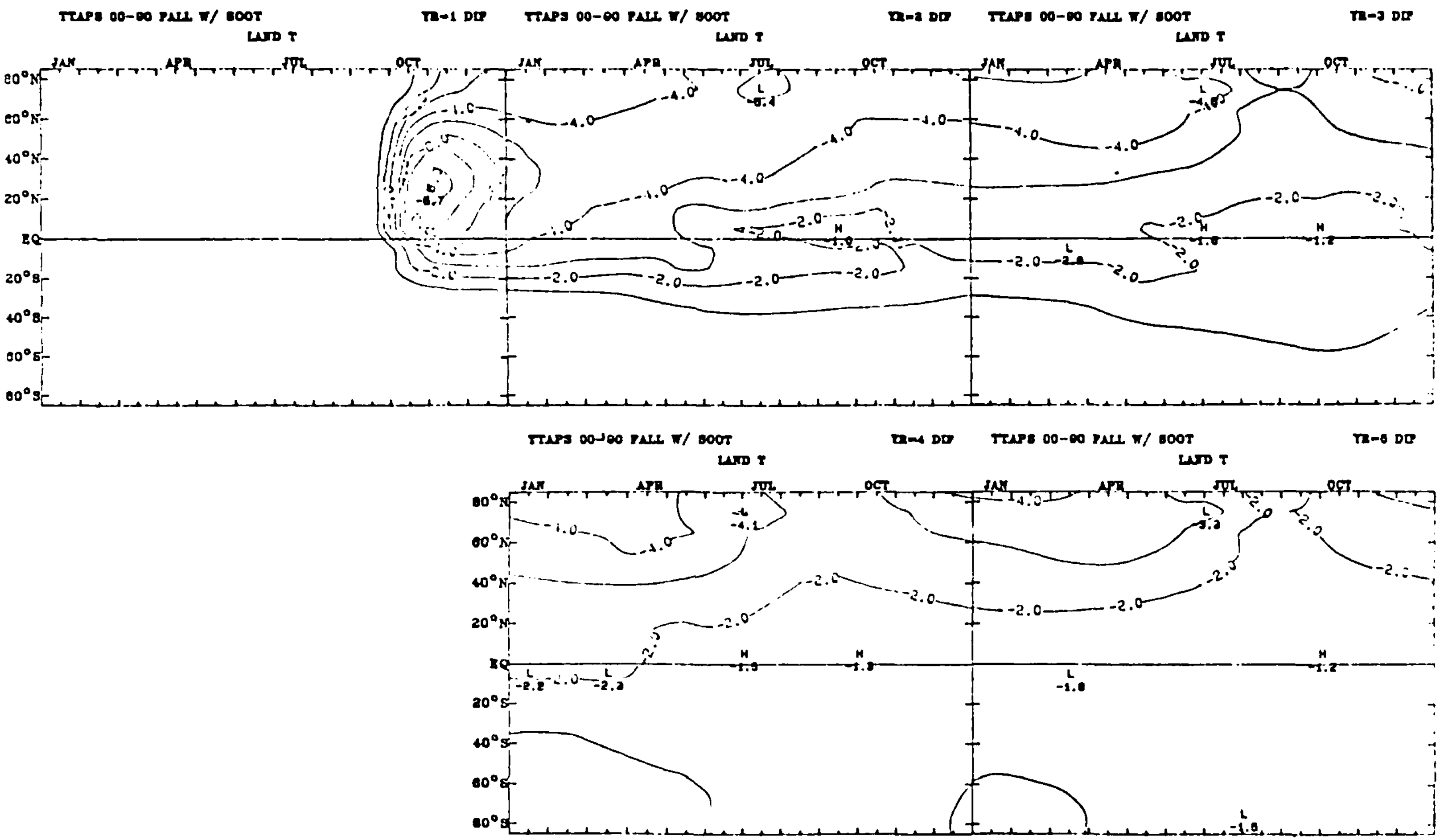

TTAPS 00-90 FALL W/ SOOT
LAND T
YR-1 DIF
YR-2 DIF
YR-3 DIF
YR-4 DIF
YR-5 DIF
JAN
APR
JUL
OCT
80°N
60°N
40°N
20°N
EQ
20°S
40°S
60°S
80°S

Figure 15

SECTION 2

FIELD MEASUREMENTS AND INSTRUMENTATION

AN EXPERIMENTAL PROTOCOL FOR AIRCRAFT OBSERVATIONS OF THE AEROSOLS AND GASES FROM LARGE FIRES

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The robustness of the nuclear winter scenario depends critically on a number of uncertain factors, some of which can be experimentally examined by studying large prescribed fires. We describe here the experimental protocol used to study the following issues:

1) "Prompt removal" of smoke by fire capping cumulus clouds

2) Unusual microphysical characteristics of both fire capping cumulus and other clouds later ingesting the smoke.

3) Variations in particle and gaseous emissions with fire size and fuel mix

4) Radiative properties of the smokes

5) Time evolution of dense smokes with emphasis on aerosol coagulation, and changes in morphology and radiative properties.

Abstract for the 25-27 February 1986 Global Effects Program Technical Meeting.

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title: The 1986 field experiment at the San Dimas Experimental Forest (Lodi Canyon), Los Angeles County.

An overview will be presented of the current plans for the 420 hectare, high-intensity prescribed fire in Los Angeles County. Plans for conducting the fire, research coordination, expected fire behavior, measurements of fire physics, and organization of fire management will be discussed.

FIELD-SCALE MEASUREMENTS OF EMISSIONS FROM OPEN FIRES

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WHY EMISSIONS CHARACTERIZATION RESEARCH?

- EMISSIONS FROM OPEN FIRES ARE KNOWN TO BE HARMFUL TO HUMAN HEALTH.
- EMISSIONS FROM PRESCRIBED FIRES CAN BE REDUCED.
- SOURCE STRENGTH DATA ARE NEEDED TO MANAGE SMOKE.
- FINGERPRINTING METHODS ARE NEEDED TO IMPROVE THE ASSESSMENT OF IMPACTS AT RECEPTOR SITES.

WHAT IS RESEARCH DOING?

- DEVELOPING FUEL CONSUMPTION ALGORITHMS FOR PREDICTING THE CONSUMPTION OF FUEL AS FUNCTIONS OF MOISTURE CONTENT AND METHOD OF BURNING.
- CHARACTERIZING EMISSIONS FROM OPEN FIRES AS FUNCTIONS OF FUEL AND FIRE BEHAVIOR.

    A. EMISSION FACTORS.
    B. SOURCE STRENGTH.
    C. SIGNATURE COMPOUNDS.
        1. CARBON
        2. POM'S
        3. HALOGENATED HYDROCARBONS

HOW ARE THE DATA BEING USED?

- TECHNIQUES OF BURNING TO MINIMIZE THE PRODUCTION OF AIR POLLUTANTS (SOURCE MODELS)
- UPDATE NATIONAL AND REGIONAL EMISSION INVENTORIES (SANDBERG AND PETERSON 1985, CHI ET AL. 1979)
- TRADEOFFS BETWEEN SMOKE FROM WILD FIRES AND PRESCRIBED FIRES (COOPER 1976)
- AN ASSESSMENT OF EMISSIONS PRODUCTION AS A FUNCTION OF INCREASED WOOD UTILIZATION (SANDBERG AND WARD 1982)
- A MODEL(S) TO PROVIDE DATA ON SOURCE STRENGTH FOR SMOKE DISPERSION CALCULATIONS (PIEROVICH 1983)
- SOURCE CHARACTERISTICS FOR ASSESSING IMPACT OF BURNING OF FOREST MATERIALS ON REGIONAL HAZE (CORE ET AL. 1983, 1984, 1985)
- CHARACTERISTICS AND SOURCE TERMS FOR PROJECTIONS OF NUCLEAR WINTER PHENOMENA (CORRESPONDENCE 1981 TO PRESENT)

  ■■■NEED DATA FOR HIGHER INTENSITY FIRES■■■
- DATABASE OF EMISSIONS DATA AND RESEARCH.

  ■■■NEED TO EXPAND ON EFFORT UNDERWAY■■■

FUTURE WORK IN OREGON, WASHINGTON, AND CALIFORNIA

●●(1986) WHAT ARE WE DOING NOW?

- PILED SLASH (WESTSIDE OF CASCADES)--6 SAMPLES
- BROADCAST BURNS OF HARDWOOD SLASH--6 SAMPLES
- BROADCAST BURNS OF LONG-NEEDLED CONIFER SLASH EAST OF CASCADES--4 TO 6 SAMPLES.
- LODI EXPERIMENT--4 TO 6 SAMPLES OF CHAPARRAL?

●●(1987-   ) WHAT WILL WE BE DOING?

- SLASH VS. GRASS
- HERBICIDE TREATED UNITS
  - PRODUCTS OF DECOMPOSITION
  - EFFECTIVENESS OF HERBICIDE TREATMENTS.
- PARTIALLY CUT UNITS (LINE FIRES IN CONIFER TYPES).
- PILED SLASH VS. BROADCAST VS. PARTIALLY CUT
- BRUSH SPECIES
  - BITTERBRUSH
  - SAGEBRUSH
  - CEANOTHUS
  - CHAPARRAL
- COMBUSTION AND FUEL CHEMISTRY AFFECTING PRODUCTION OF TRACE MATERIALS. (COMBUSTION HOOD RESEARCH.)

HOW DO WE MEASURE EMISSIONS FROM OPEN FIRES?

A. SURFACE SAMPLING

1. Vertical array--LINE FIRES
2. Horizontal array--AREA FIRES
3. Traversing in horizontal plane--PILED MATERIAL OR POOL FIRES

B. AIRBORNE SAMPLING SYSTEMS

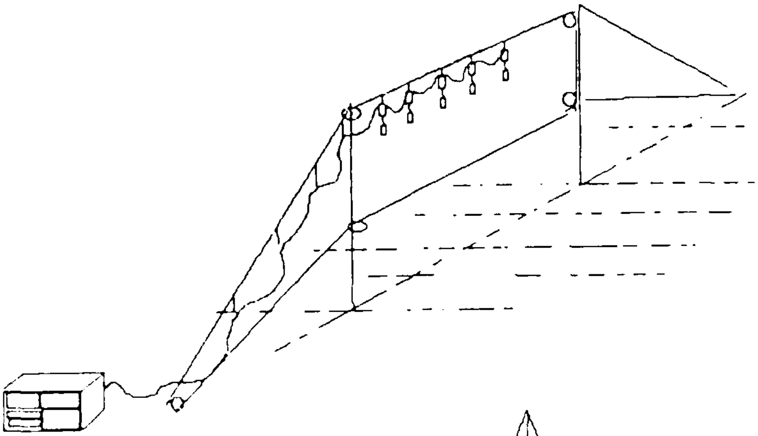
EMISSION MEASUREMENTS

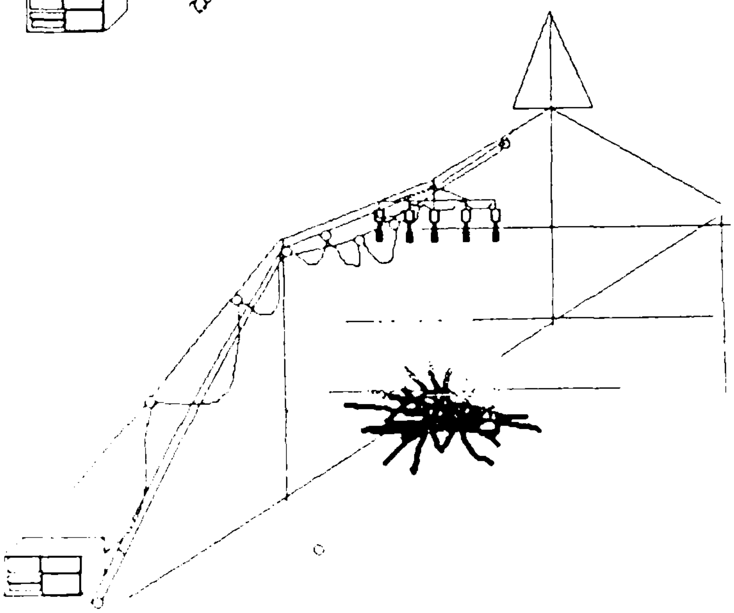
A. EMISSION FACTORS

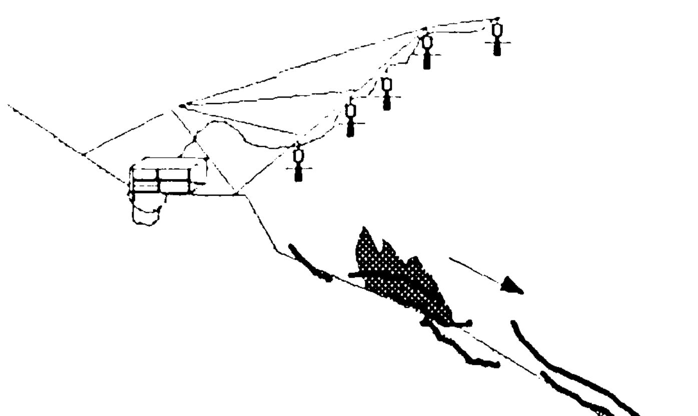
1. CARBON-MASS BALANCE
2. EMISSION FLUX/FUEL CONSUMPTION

B. SOURCE STRENGTH

1. EMISSION FLUX
2. FUEL CONSUMPTION X EF







SAMPLING MATRIX

I. PARTICULATE MATTER

A. 47-MM GLASS FIBER
B. 47-MM GLASS FIBER BACKED WITH POLYURETHANE FOAM
C. 37-MM QUARTZ
D. 37-MM TEFLON
E. 20- X 25-CM GLASS FIBER (HI-VOL)

II. GASES

A. GRAB SAMPLES
   1. BAG SAMPLES FOR COMBUSTION GAS ANALYSIS.
   2. ADSORPTION TUBES.
   3. CANISTER SAMPLES FOR TRACE GASES.
B. REAL TIME GAS ANALYSIS
   1. CO (1 TO 40 PERCENT OF CARBON)
   2. CO_2 (50 TO 95+ PERCENT OF CARBON)

III. OTHER SENSORS

A. TEMPERATURE (TYPE K T/C, 0 °C COMPENSATED)
B. COMBUSTION GAS VELOCITY (VANE ANEMOMETERS, KURZ MASS-FLOW METERS)

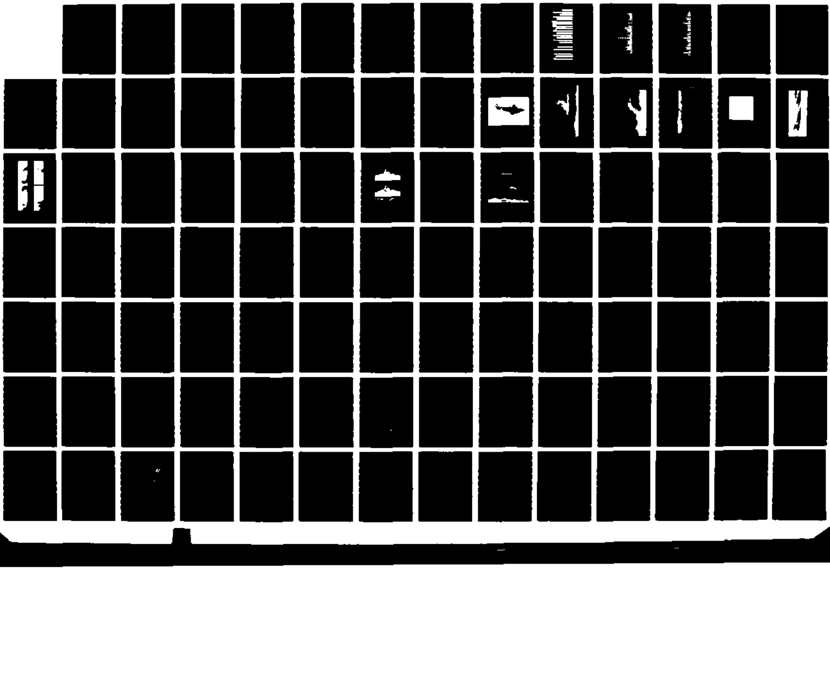
IV. DATA LOGGER (FLUKE 2280A)

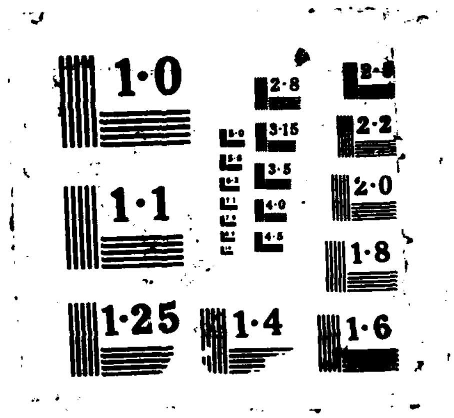
V. GAS SAMPLING IS CONTINUOUS

A. 5 TEFLON TUBES 100 M X 3/16" ID (2 LITERS/MIN)
B. 3 NYLON TUBES 100 M X 1/4" ID (10 LITERS/MIN)
C. 2 NYLON TUBES 100 M X 1/4" ID (5 LITERS/MIN)

AD-A185 151 TECHNICAL PAPERS PRESENTED AT THE DEFENSE NUCLEAR AGENCY GLOBAL EFFECTS R.. (U) DOD NUCLEAR INFORMATION AND ANALYSIS CENTER SANTA BARBARA CA.. 15 MAY 86 3/4

UNCLASSIFIED DASIAC-TN-86-29-VOL-3 DNA001-82-C-0274 F/G 15/6.4 NL




1·0
2·8
3·15
3·5
4·0
4·5
2·2
2·0
1·1
1·8
1·25
1·4
1·6

EMISSIONS ANALYSIS MATRIX

I. PARTICULATE MATTER

A. PM

1. TOTAL PARTICULATE MATTER $EF_{PM[F]}$ AND $EF_{PM[S]}$
2. POM PROFILING (B[A]P)
3. LIGHT ABSORPTION

B. PM2.5

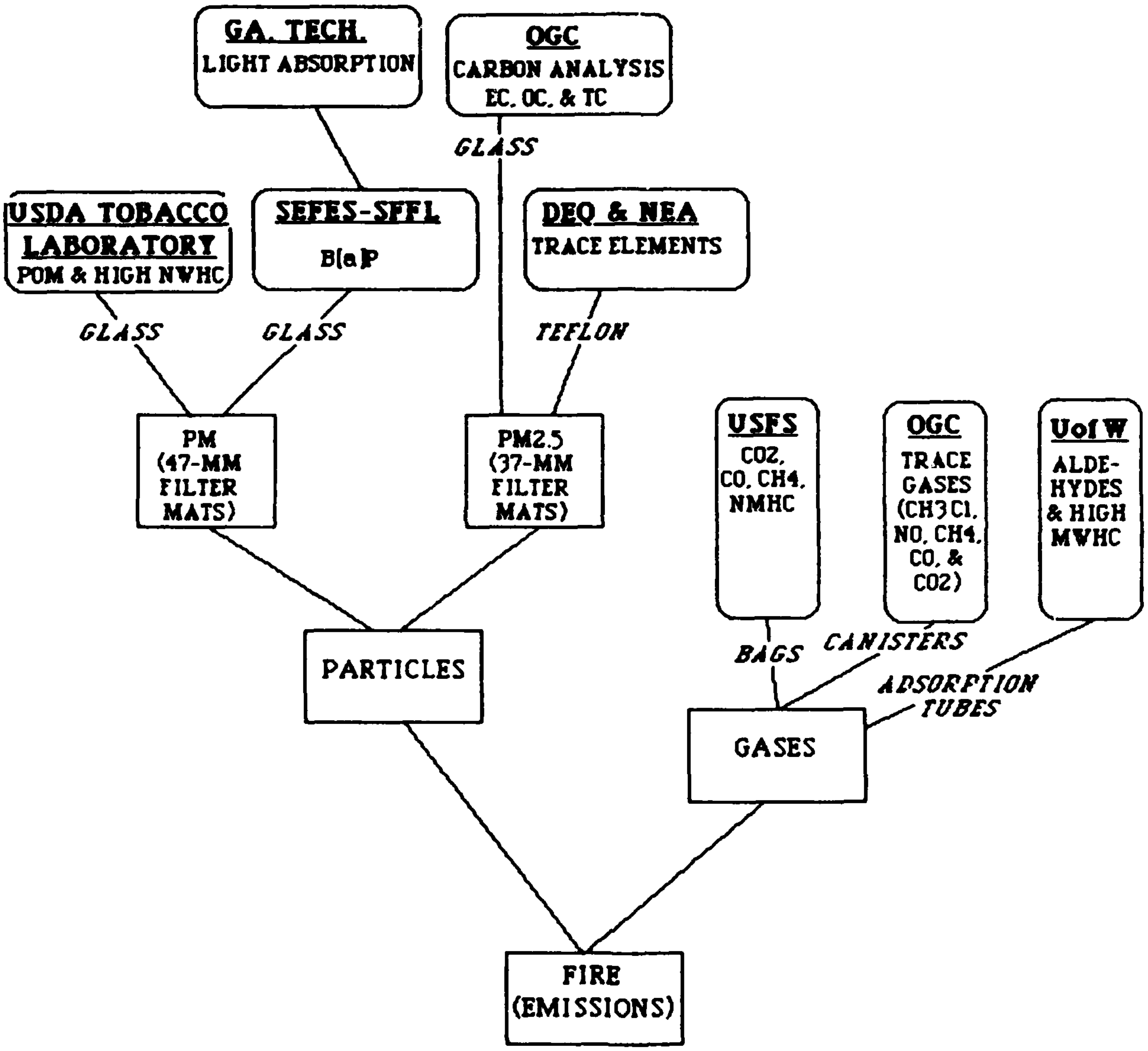
1. PARTICULATE MATTER LESS THAN A MEAN CUTPOINT DIAMETER OF 2.5 µM ($EF_{PM2.5[F]}$ AND $EF_{PM2.5[S]}$)
2. CARBON ANALYSIS
   A. GRAPHYTIC
   B. ORGANIC
   C. TOTAL CARBON

II. GASES

A. BAG GRAB SAMPLES (CO, CO_2, CH_4, NMHC)

B. CANISTERS (CH_3CL, NO_2, CH_4, CO_2, COS, ETC.)

C. ADSORPTION TUBES (ALDEHYDES AND OTHER HEAVY MWHC)


GA. TECH.
LIGHT ABSORPTION
OGC
CARBON ANALYSIS
EC, OC, & TC
GLASS
USDA TOBACCO LABORATORY
POM & HIGH MWHC
SEFES-SFFL
B(a)P
DEQ & NEA
TRACE ELEMENTS
GLASS
GLASS
TEFLON
PM (47-MM FILTER MATS)
PM2.5 (37-MM FILTER MATS)
USFS
CO2, CO, CH4, NMHC
OGC
TRACE GASES (CH3Cl, NO, CH4, CO, & CO2)
U of W
ALDEHYDES & HIGH MWHC
BAGS
CANISTERS
ADSORPTION TUBES
PARTICLES
GASES
FIRE (EMISSIONS)

TEST LOCATION	FIRE PHASE	Carbon (mg/m3)	Combustion effic. (%)	EMISSION FACTORS (G/KG) CO2	CO	CH4	NMHC	PM 2.5	PM	FUEL CONSUMPT.	Heat releas. (kw/m2)	TOTAL PM2.5
CAT	F	746.0	89.0%	1625.0	112.0	1.8	1.1	13.0	15.4	2.7	28.9	35.6
HEBO	F	683.0	88.0%	1632.0	94.0	4.2	3.6	15.9	23.4	1.3	53.3	19.9
MARIA 1	F	755.0	89.0%	1635.0	101.0	2.2	2.3	12.2	23.5	8.5	68.0	103.7
MARIA 2	F											
DLAKE 1	F	1389.0	90.0%	1659.0	82.0				10.2		48.6 -	
DLAKE 2	F	1938.0	94.0%	1720.0	56.0	1.9	1.9	5.5	11.6	6.2	83.2	34.3
BE 1	F	182.3	93.0%	1704.6	66.4	3.0	3.2	6.6	10.8	0.8	20.16	5.4
BE 2	F	1011.8	94.9%	1739.1	49.7	1.9	1.1	4.2	8.2	2.8	69.34	11.7
BE 3	F	1461.2	97.2%	1781.4	28.3	0.7	1.2	1.2	4.2	3.2	78.88	3.7
WCB 1	F	2337.4	93.6%	1716.1	62.6	2.0	1.7	4.4	6.0	0.8		3.5
WCB 2	F	1623.7	93.3%	1711.3	63.1	2.7	2.6	4.1	10.1	6.3	155.77	25.7
WCB3	F									0.6	15.16	
CAT	S1	216.0	80.0%	1468.0	198.0	6.8	3.2	17.6	13.8	4.6	5.0	81.5
HEBO	S1	72.0	77.0%	1413.0	231.0	7.8	3.0	14.0	12.2	13.9		194.9
MARIA 1	S1	634.0	79.0%	1455.0	201.0	7.1	3.9	14.0	20.4	13.9	38.5	194.9
MARIA 2	S1	23.0	63.0%	1146.0	359.0	2.4	2.4		34.2			
DLAKE 1	S1	144.0	85.0%	1555.0	130.0				14.1		1.7	
DLAKE 2	S1	268.0	80.0%	1458.0	196.0	4.6	4.6	11.4	14.1	9.1	10.0	103.3
BE 1	S1	278.0	75.5%	1384.9	232.7	10.6	6.8	18.2	24.0	1.6	6.78	29.4
BE 2	S1	309.2	78.1%	1432.5	222.1	7.9	2.2	12.8	17.9	2.3	9.76	29.9
BE 3	S1	863.0	77.5%	1421.7	220.4	8.1	5.2	14.9	19.5	5.4	22.71	80.7
WCB 1	S1	176.1	75.8%	1390.0	251.0	7.9	3.2	10.7	15.6	2.8		30.2
WCB 2	S1	290.5	74.8%	1370.4	251.6	9.3	7.2	11.1	19.7	2.2	9.03	23.9
WCB3	S1									3.09	12.94	
CAT	S2	65.0	81.0%	1483.0	197.0	5.7	2.8	9.3	11.7	0.3		2.6
HEBO	S2											
MARIA 1	S2	138.0	74.0%	1364.0	260.0	7.6	3.4	12.0	20.3	3.5	1.0	41.4
MARIA 2	S2	34.0	66.0%	1204.0	358.0	1.2	1.2		25.8			
DLAKE 1	S2	95.0	77.0%	1403.0	156.0				13.4			
DLAKE 2	S2	75.0	78.0%	1427.0	222.0	3.6	3.6	12.7	12.4	0.5		6.7
BE 1	S2	47.4	81.7%	1497.9	179.5	10.4	9.7	8.2	12.0	0.9	1.79	6.9
BE 2	S2	30.8	94.4%	1729.8	53.9	4.0	2.5	5.7	4.8	0.3	0.53	1.4
BE 3	S2	95.8	77.8%	1425.5	248.0	6.6	0.0	0.0	14.3	0.6	1.27	
WCB 1	S2	32.4	65.5%	1200.3	393.1	3.0	0.0	3.8	7.1	1.0		4.0
WCB 2	S2	33.3	55.3%	1014.1	459.6	7.2	19.3	10.6	17.4	0.4	0.86	4.4

Table IX Percent elemental composition of PM2.5 for specific trace elements and ions by combustion phase.

TEST LOCATION	FIRE PHASE	TRACE ELEMENTS (PERCENT OF PM2.5) Na	Al	Si	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Br	Pb	SO4	NO3	NH4
CAT	F		0.102	0.094	0.204	0.568	0.589	0.201				0.018	0.032								
HEBO	F		0.101	0.409	0.403	1.054	1.960	0.030				0.008	0.018								
MARIA 1	F		0.164	0.189	0.375	1.048	1.323	0.099				0.006	0.039								
MARIA 2	F																				
DLAKE 1	F		0.057	0.047	0.280	0.313	1.002	0.078				0.007	0.003								
DLAKE 2	F		0.305	0.200	0.576	0.707	2.433	0.809				0.078	0.035								
BE 1	F	9.200	0.070	0.040	0.150	0.150	0.200	0.080	0.130	0.010	0.020	0.060	0.020	0.010	0.010	0.060	0.030	0.110	0.5	0.5	0.8
BE 2	F	0.902	0.084	0.050	0.254	0.391	1.435	0.102	0.160	0.018	0.042	0.075	0.044	0.007	0.007	0.091	0.046	0.127	0.5	0.7	0.4
BE 3	F	2.149	0.205	0.125	0.495	0.476	2.606	0.250	0.608	0.286	0.459	0.090	0.346	0.020	0.020	0.284	0.074	0.320	1.2	1.5	0.9
WCB 1	F	0.920	0.044	0.026	0.483	0.637	1.936	0.050	0.080	0.015	0.018	0.017	0.016	0.005	0.005	0.094	0.065	0.066	1.1	0.4	0.2
WCB 2	F	0.500	0.065	0.034	0.191	0.215	0.706	0.116	0.110	0.015	0.025	0.022	0.017	0.005	0.005	0.061	0.025	0.146	0.6	0.5	0.4
WCB3	F																				
CAT	S1		0.045	0.055	0.150	0.187	0.148	0.057				0.005	0.014								
HEBO	S1		0.139	0.231	0.174	0.154	0.164	0.015				0.002	0.024								
MARIA 1	S1		0.036	0.037	0.084	0.199	0.171	0.049				0.002	0.014								
MARIA 2	S1		0.079	0.377	0.030		0.069	0.144				0.020	0.169								
DLAKE 1	S1		0.118	0.337	0.110	0.045	0.147	0.179				0.016	0.078								
DLAKE 2	S1		0.086	0.105	0.037	0.037	0.216	0.066				0.002	0.030								
BE 1	S1	0.409	0.010	0.010	0.030	0.037	0.063	0.023	0.026		0.004	0.013					0.010	0.020	0.1	0.2	0.1
BE 2	S1	0.152	0.012	0.012	0.059	0.102	0.079	0.128	0.020	0.002	0.005	0.016	0.017				0.005	0.018	0.1	0.1	0.1
BE 3	S1	0.128	0.014	0.010	0.038	0.081	0.158	0.102	0.016		0.010	0.014	0.010					0.010	0.1	0.1	0.1
WCB 1	S1	0.457	0.026	0.024	0.076	0.049	0.115	0.039	0.059	0.010	0.010	0.010	0.010				0.018	0.035	0.3	0.2	0.2
WCB 2	S1	0.200	0.033	0.010	0.076	0.072	0.042	0.125	0.035	0.005	0.005	0.005	0.010					0.025	0.1	0.1	0.1
WCB3	S1																				
CAT	S2		0.697	1.299	0.304	0.220	0.289	0.742				0.096	0.533								
HEBO	S2																				
MARIA 1	S2																				
MARIA 2	S2		0.073	0.118	0.020	0.185	0.060	0.123				0.010	0.025								
DLAKE 1	S2		0.088	0.285	0.109	0.034	0.098	0.057				0.010	0.054								
DLAKE 2	S2																				
BE 1	S2	0.793	0.069	0.111	0.152	0.069	0.054	0.089	0.145	0.013	0.026	0.026	0.076	0.003	0.003	0.003	0.065	0.061	0.4	0.6	0.3
BE 2	S2	1.558	0.115	0.081	0.277	0.130	0.040	0.237	0.267	0.024	0.047	0.049	0.034	0.010	0.010	0.016	0.024	0.195	0.8	1.0	0.8
BE 3	S2																				
WCB 1	S2	2.469	0.222	0.145	0.208	0.239	0.079	0.263	0.461	0.053	0.092	0.092	0.069	0.016	0.016	0.026	0.049	0.264	1.4	2.3	1.4
WCB 2	S2	1.027	0.087	0.050	0.230	0.098	0.073	0.117	0.197	0.124	0.034	0.038	0.030	0.010	0.010	0.018	0.014	0.141	0.6	0.7	0.4

Table XII Percent elemental, organic, and total carbon content of PM2.5 by combustion phase.

TEST	FIRE	EF (g/kg)		PERCENT OF PM2.5		
LOCATION	PHASE	PM 2.5	PM	Org. C	El. C	Total C
CAT	F	13.0	15.4	50.4	5.6	56.0
HEBO	F	15.9	23.4	42.0	8.0	50.0
MARIA 1	[illegible]	12.2	27.5			
MARIA 2	[illegible]	[illegible]	[illegible]			
DLAKE 1	F		10.2			
DLAKE 2	F	5.5	11.6	42.0	12.0	54.0
BE 1	F	6.6	10.8	30.6	20.0	50.6
BE 2	F	4.2	8.2	16.8	40.3	57.1
BE 3	F	1.2	4.2	24.9	34.1	59.0
WCB 1	F	4.4	6.0	41.9	10.6	52.5
WCB 2	F	4.1	10.1	42.8	18.4	[illegible]
WCB3	F					
CAT	S1	17.6	13.8	45.6	3.4	49.0
HEBO	S1	14.0	12.2			
MARIA 1	S1	14.0	20.4	51.0	2.7	53.7
MARIA 2	S1		34.2			
DLAKE 1	S1		14.1			
DLAKE 2	S1	11.4	14.1	45.0	3.2	48.2
BE 1	S1	18.2	24.0	55.6	3.2	58.8
BE 2	S1	12.8	17.9	55.1	4.9	60.0
BE 3	S1	14.9	19.5	62.6	2.5	65.1
WCB 1	S1	10.7	15.6	46.8	5.7	52.5
WCB 2	S1	11.1	19.7	62.3	2.7	65.0
WCB3	S1					
CAT	S2	9.3	11.7			
HEBO	S2					
MARIA 1	S2	12.0	20.3			
MARIA 2	S2		25.8	36.0	2.7	38.7
DLAKE 1	S2		13.4			
DLAKE 2	S2	12.7	12.4			
BE 1	S2	8.2	12.0			
BE 2	S2	5.7	4.8			
BE 3	S2	0.0	14.3			
WCB 1	S2	3.8	7.1	62.6	2.6	65.2
WCB 2	S2	10.6	17.4	60.7	4.5	65.2

Table VIII Correlation matrix for variables measured during 1983 and 1984 tests (F and S1 data only).

	YEAR	PHKE	EFCY	EFCO2	EFCO	EFCH4	EFNM	EF25	EFPM
PHKE	-0.045								
EFCY	0.130	-0.876							
EFCO2	0.127	-0.877	0.999						
EFCO	-0.008	0.881	-0.996	-0.997					
EFCH4	0.182	0.824	-0.877	-0.868	0.862				
EFNM	0.181	0.613	-0.548	-0.540	0.529	0.788			
EF25	-0.414	0.845	-0.776	-0.764	0.735	0.718	0.555		
EFPM	-0.208	0.480	-0.750	-0.743	0.712	0.347	0.422	0.812	
W	-0.334	0.346	-0.275	-0.276	0.272	0.143	0.058	0.101	0.114
IR	0.101	-0.705	0.723	0.728	-0.711	-0.884	-0.486	-0.884	-0.420
POC	-0.083	0.867	-0.796	-0.797	0.787	0.756	0.662	0.865	0.731
PEC	0.363	-0.871	0.777	0.775	-0.759	-0.877	-0.383	-0.776	-0.721
PTC	0.382	0.143	-0.108	-0.173	0.185	0.289	0.276	-0.088	0.138
PNA		-0.400	0.429	0.430	-0.434	-0.385	-0.164	-0.298	-0.312
PAL	-0.307	-0.466	0.475	0.467	-0.478	-0.807	-0.481	-0.431	-0.234
PSI	-0.608	0.080	-0.190	-0.199	0.137	-0.411	-0.343	-0.081	0.300
PS	-0.106	-0.780	0.762	0.765	-0.765	-0.672	-0.568	-0.556	-0.460
PCL	-0.334	-0.730	0.586	0.602	-0.807	-0.849	-0.490	-0.166	0.065
PK	-0.008	-0.773	0.743	0.746	-0.749	-0.848	-0.534	-0.598	-0.431
PCA	-0.170	-0.298	0.322	0.309	-0.312	-0.392	-0.306	-0.398	-0.177
PMN	0.325	-0.538	0.589	0.588	-0.578	-0.589	-0.495	-0.748	-0.486
PFE	0.084	-0.126	0.114	0.103	-0.111	-0.472	-0.371	-0.508	-0.089
EFOC	-0.233	0.750	-0.856	-0.846	0.824	0.831	0.874	0.961	0.888
EFEC	0.055	-0.581	0.487	0.490	-0.507	-0.392	-0.375	-0.197	-0.147
EFTC	-0.235	0.707	-0.827	-0.818	0.792	0.814	0.653	0.974	0.905
EFNA		-0.316	0.257	0.257	-0.265	-0.202	-0.013	-0.105	-0.121
EFAL	-0.839	-0.254	0.102	0.100	-0.129	-0.253	-0.217	0.241	0.229
EFSI	-0.780	-0.029	-0.079	-0.072	0.057	-0.073	-0.149	0.349	0.217
EFS	-0.838	-0.427	0.246	0.269	-0.296	-0.303	-0.250	0.249	0.313
EFCL	-0.570	-0.435	0.224	0.248	-0.281	-0.301	-0.197	0.292	0.457
EFK	-0.463	-0.551	0.384	0.400	-0.443	-0.411	-0.242	0.074	0.271
EFCA	-0.335	-0.143	0.107	0.095	-0.098	-0.165	-0.147	-0.003	0.099
EFMN	0.207	-0.385	0.393	0.387	-0.387	-0.257	-0.219	-0.240	-0.144
EFFE	-0.820	-0.130	0.080	0.088	-0.101	-0.290	-0.297	0.252	0.197
EFBAP		-0.308	0.432	0.452	-0.464	0.048	0.299	0.489	-0.037
TAVG	-0.004	-0.825	0.787	0.781	-0.772	-0.703	-0.830	-0.798	-0.798
TMAX	0.200		0.654	0.652	-0.867	-0.368	-0.322	-0.828	-0.830

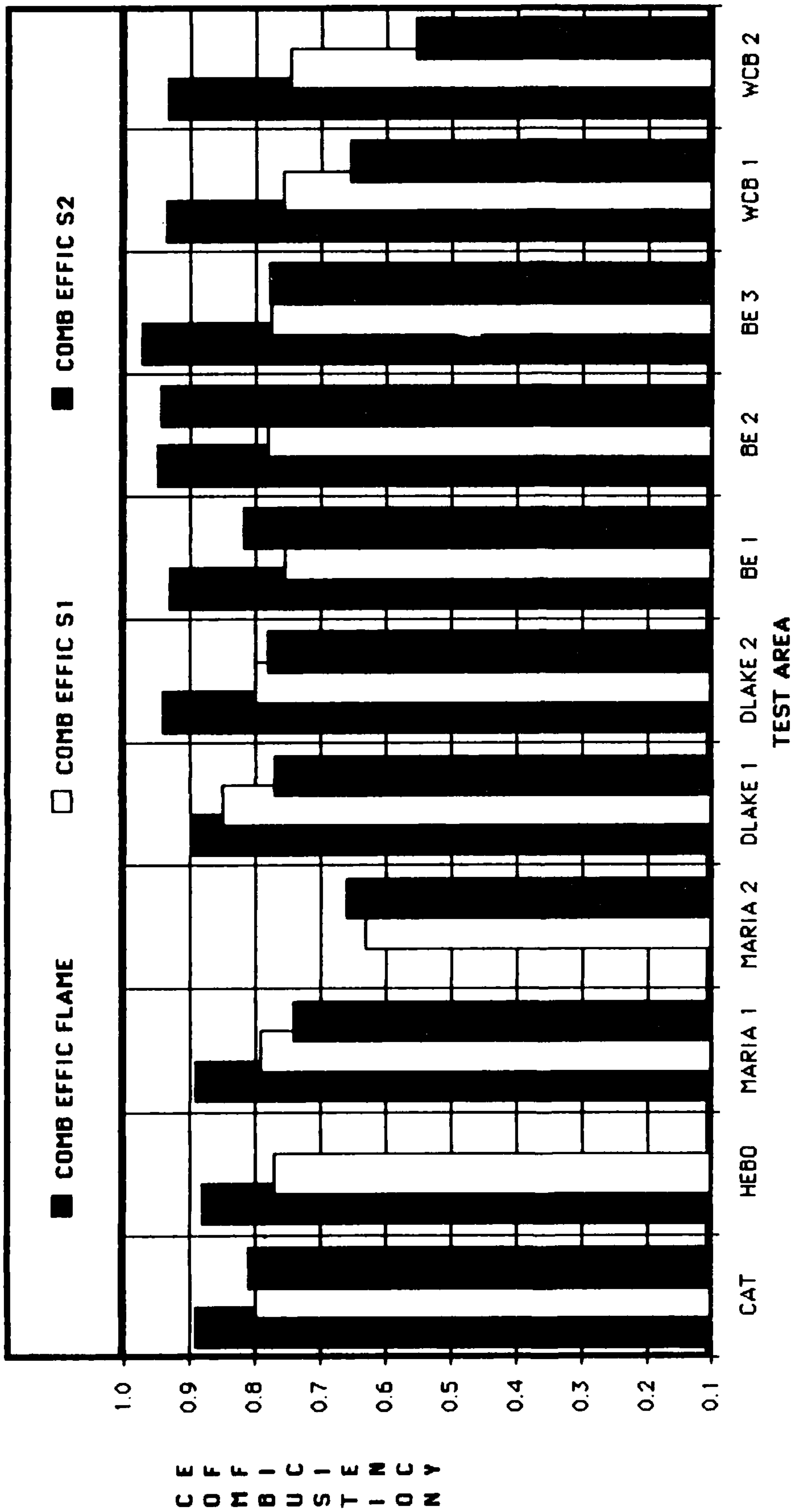
	W	IR	POC	PEC	PTC	PNA	PAL	PSI	PS	PCL
PHKE										
EFCY										
EFCO2										
EFCO										
EFCH4										
EFNM										
EF25										
EFPM										
W										
IR	0.190									
POC	0.196	-0.464								
PEC	-0.223	0.604	-0.903							
PTC	-0.027	0.233	0.369	0.067						
PNA	-0.406	-0.075	-0.450	0.305	-0.574					
PAL	0.217	0.481	-0.464	0.417	-0.176	0.285				
PSI	0.407	0.076	-0.391	0.241	-0.387	0.265	0.556			
PS	-0.151	0.629	-0.539	0.482	-0.209	0.116	0.717	0.103		
PCL	-0.122	0.455	-0.366	0.256	-0.294	0.040	0.542	0.234	0.814	
PK	-0.204	0.661	-0.592	0.574	-0.133	-0.002	0.675	0.064	0.958	0.776
PCA	-0.005	0.331	-0.123	0.163	0.065	0.019	0.772	0.304	0.519	0.270
PMN	-0.294	0.459	-0.759	0.844	0.063	0.485	0.577	0.065	0.527	0.196
PFE	-0.066	0.327	-0.490	0.507	0.144	0.000	0.431	0.414	0.275	0.124
EFOC	0.136	-0.877	0.826	-0.818	0.153	-0.386	-0.550	-0.305	-0.639	-0.333
EFEC	-0.431	0.195	-0.650	0.578	-0.260	0.480	0.098	0.092	0.192	0.363
EFTC	0.065	-0.666	0.775	-0.774	0.128	-0.345	-0.560	-0.309	-0.640	-0.299
EFNA	-0.449	-0.218	-0.299	0.134	-0.567	0.972	0.059	0.042	-0.082	-0.120
EFAL	0.418	0.132	-0.050	-0.174	-0.494	0.605	0.834	0.843	0.385	0.601
EFSI	0.542	0.036	-0.005	-0.277	-0.611	0.363	0.449	0.844	0.200	0.413
EFS	-0.009	0.142	-0.079	-0.120	-0.443	0.004	0.411	0.551	0.557	0.833
EFCL	-0.049	0.127	-0.020	-0.139	-0.347	-0.075	0.283	0.421	0.440	0.857
EFK	-0.147	0.267	-0.180	0.031	-0.350	-0.111	0.416	0.430	0.625	0.895
EFCA	0.008	0.032	0.284	-0.231	0.114	-0.263	0.508	0.292	0.265	0.237
EFMN	-0.453	0.034	-0.299	0.336	0.031	0.034	0.280	-0.024	0.108	0.008
EFFE	0.300	-0.003	-0.165	0.065	-0.236	0.051	0.475	0.881	0.215	0.437
EFBAP	-0.310	-0.093	-0.130	-0.293	-0.497	0.000	-0.196	-0.341	0.153	0.448
TAVG	0.242	0.773	-0.673	0.692	-0.213	-0.011	0.876	0.433	0.889	0.235
TMAX	0.123	0.366	0.012	0.137	0.527	-0.850	0.317	0.000	0.475	-0.280

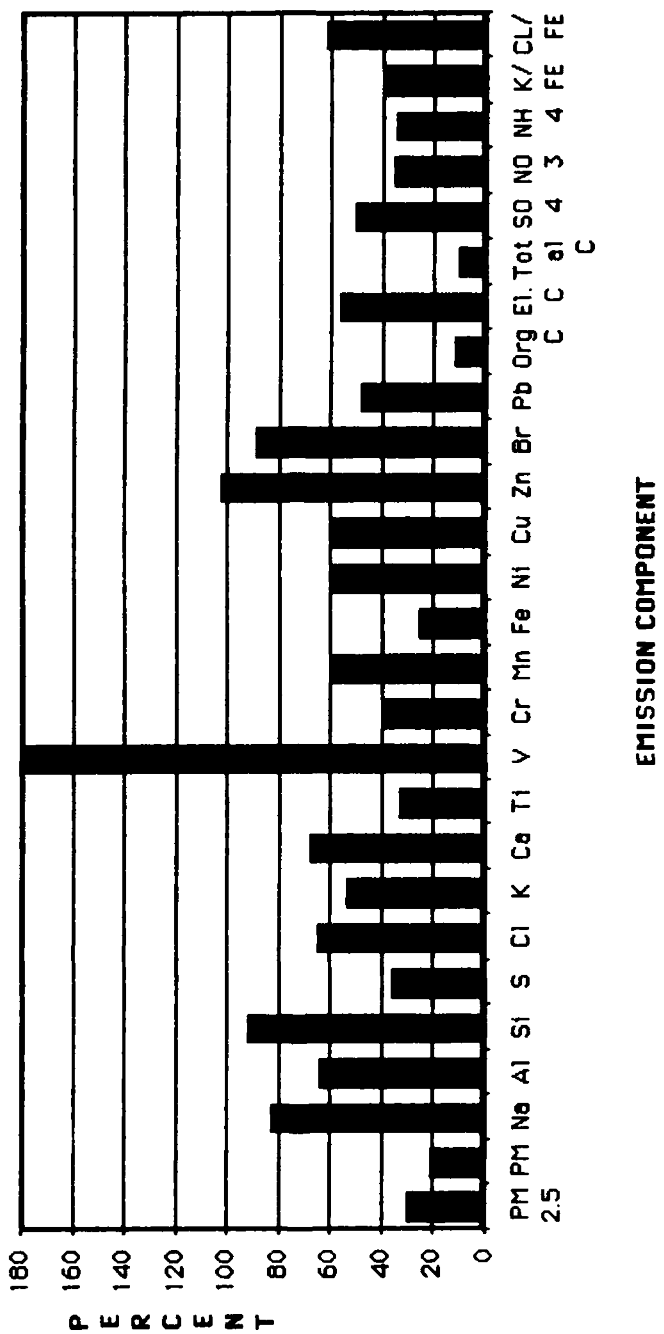
	PK	PCA	PMN	PFE	EFOC	EFEC	EFTC	EFNA	EFAL	EFSI
PCA	0.498									
PMN	0.810	0.395								
PFE	0.398	0.209	0.549							
EFOC	-0.844	-0.333	-0.742	-0.471						
EFEC	0.217	-0.064	0.408	-0.145	-0.370					
EFTC	-0.842	-0.355	-0.718	-0.513	0.993	-0.255				
EFNA	-0.211	-0.182	0.305	-0.125	-0.215	0.488	-0.164			
EFAL	0.248	0.271	-0.140	-0.141	0.028	0.203	0.056	0.680		
EFSI	0.061	-0.012	-0.304	-0.136	0.180	0.168	0.209	0.623	0.929	
EFS	0.453	0.123	-0.152	-0.168	0.061	0.356	0.110	0.089	0.773	0.854
EFCL	0.389	-0.006	-0.209	-0.128	0.160	0.389	0.215	-0.081	0.681	0.550
EFK	0.818	0.183	0.008	-0.062	-0.067	0.413	-0.016	-0.197	0.608	0.440
EFCA	0.198	0.851	0.229	-0.147	0.083	-0.143	0.068	-0.182	0.355	0.076
EFMN	0.207	0.563	0.860	-0.048	-0.219	0.559	-0.155	0.890	-0.040	-0.256
EFFE	0.205	0.033	-0.021	0.413	0.106	-0.051	0.106	-0.118	0.651	0.857
EFBAP	0.178	-0.499	-0.334	-0.468	0.528	0.589	0.606	0.000	0.213	0.272
TAVG	0.748	0.625	0.777	0.453	-0.813	0.205	-0.824	-0.195	0.064	-0.093
TMAX	0.544	0.688	0.800	0.332	-0.463	-0.597	-0.554	-0.912	-0.315	-0.513

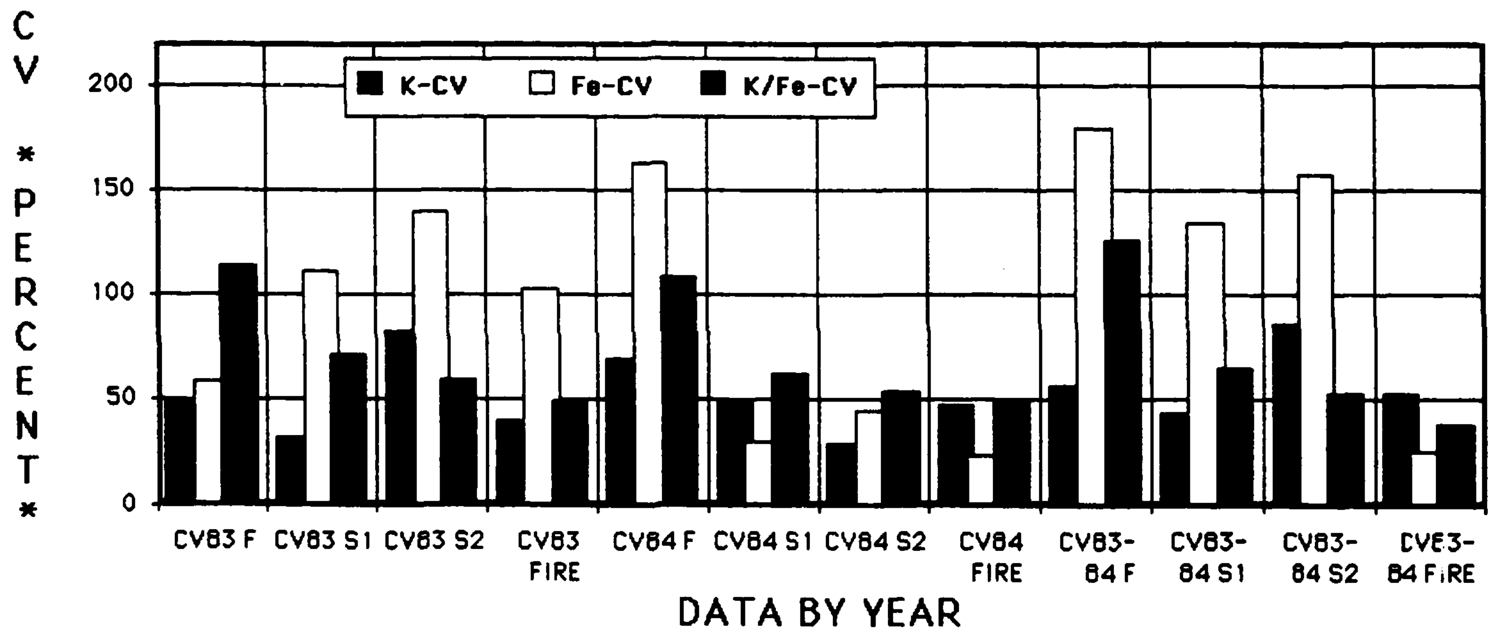
	EFS	EFCL	EFK	EFCA	EFMN	EFFE	EFBAP	TAVG
PCA								
PMN								
PFE								
EFOC								
EFEC								
EFTC								
EFNA								
EFAL								
EFSI								
EFS								
EFCL	0.943							
EFK	0.917	0.920						
EFCA	0.201	0.132	0.177					
EFMN	-0.022	-0.063	0.075	0.524				
EFFE	0.412	0.409	0.309	0.105	-0.108			
EFBAP	0.546	0.745	0.571	-0.375	-0.495	0.308		
TAVG	-0.012	-0.148	0.115	0.225	0.282	-0.091	-0.876	
TMAX	-0.364	-0.322	-0.217	0.377	0.239	-0.411	-0.868	0.981

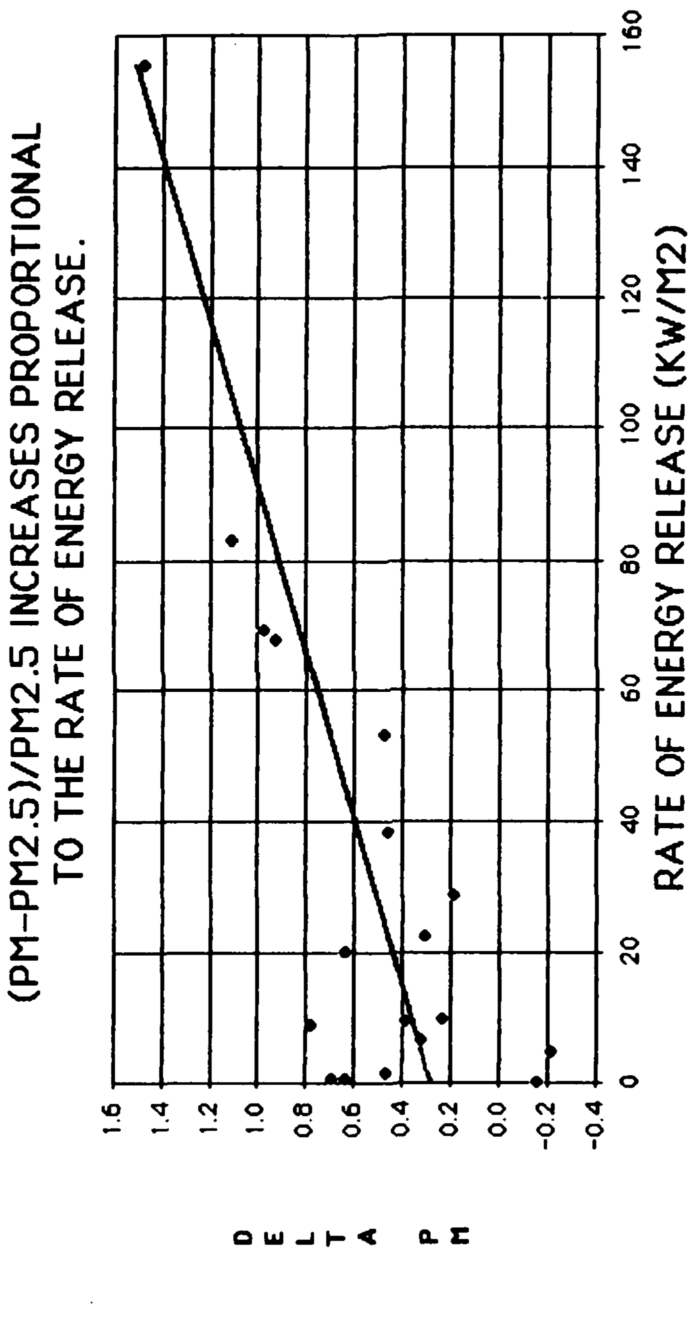
Table IX Percent elemental composition of PM2.5 for specific trace elements and ions by combustion phase.

TEST LOCATION	FIRE PHASE	Na	Al	Si	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Br	Pb	SO4	NO3	NH4
		TRACE ELEMENTS (PERCENT OF PM2.5)																			
CAT	F		0.102	0.094	0.204	0.568	0.589	0.201				0.018	0.032								
HEBO	F		0.101	0.409	0.403	1.054	1.960	0.030				0.008	0.018								
MARIA 1	F		0.164	0.189	0.375	1.048	1.323	0.099				0.006	0.039								
MARIA 2	F																				
DLAKE 1	F		0.057	0.047	0.280	0.313	1.002	0.078				0.007	0.003								
DLAKE 2	F		0.305	0.200	0.576	0.707	2.433	0.809				0.078	0.035								
BE 1	F	9.200	0.070	0.040	0.150	0.150	0.200	0.080	0.130	0.010	0.020	0.060	0.020	0.010	0.010	0.060	0.030	0.110	0.5	0.5	0.8
BE 2	F	0.902	0.084	0.050	0.254	0.391	1.435	0.102	0.160	0.018	0.042	0.075	0.044	0.007	0.007	0.091	0.046	0.127	0.5	0.7	0.4
BE 3	F	2.149	0.205	0.125	0.495	0.476	2.606	0.250	0.608	0.286	0.459	0.090	0.346	0.020	0.020	0.284	0.074	0.320	1.2	1.5	0.9
WCB 1	F	0.920	0.044	0.026	0.483	0.637	1.936	0.050	0.080	0.015	0.018	0.017	0.016	0.005	0.005	0.094	0.065	0.066	1.1	0.4	0.2
WCB 2	F	0.500	0.065	0.034	0.191	0.215	0.706	0.116	0.110	0.015	0.025	0.022	0.017	0.005	0.005	0.061	0.025	0.146	0.6	0.5	0.4
WCB3	F																				
CAT	S1		0.045	0.055	0.150	0.187	0.148	0.057				0.005	0.014								
HEBO	S1		0.139	0.231	0.174	0.154	0.164	0.015				0.002	0.024								
MARIA 1	S1		0.036	0.037	0.084	0.199	0.171	0.049				0.002	0.014								
MARIA 2	S1		0.079	0.377	0.030		0.069	0.144				0.020	0.169								
DLAKE 1	S1		0.118	0.337	0.110	0.045	0.147	0.179				0.016	0.078								
DLAKE 2	S1		0.086	0.105	0.037	0.037	0.216	0.066				0.002	0.030								
BE 1	S1	0.409	0.010	0.010	0.030	0.037	0.063	0.023	0.026		0.004	0.013					0.010	0.020	0.1	0.2	0.1
BE 2	S1	0.152	0.012	0.012	0.059	0.102	0.079	0.128	0.020	0.002	0.005	0.016	0.017				0.005	0.018	0.1	0.1	0.1
BE 3	S1	0.128	0.014	0.010	0.038	0.081	0.158	0.102	0.016		0.010	0.014	0.010					0.010	0.1	0.1	0.1
WCB 1	S1	0.457	0.026	0.024	0.076	0.049	0.115	0.039	0.059	0.010	0.010	0.010	0.010				0.018	0.035	0.3	0.2	0.2
WCB 2	S1	0.200	0.033	0.010	0.076	0.072	0.042	0.125	0.035	0.005	0.005	0.005	0.010					0.025	0.1	0.1	0.1
WCB3	S1																				
CAT	S2		0.697	1.299	0.304	0.220	0.289	0.742				0.096	0.533								
HEBO	S2																				
MARIA 1	S2																				
MARIA 2	S2		0.073	0.118	0.020	0.185	0.060	0.123				0.010	0.025								
DLAKE 1	S2		0.088	0.285	0.109	0.034	0.098	0.057				0.010	0.054								
DLAKE 2	S2																				
BE 1	S2	0.793	0.069	0.111	0.152	0.069	0.054	0.089	0.145	0.013	0.026	0.026	0.076	0.003	0.003	0.003	0.065	0.061	0.4	0.6	0.3
BE 2	S2	1.558	0.115	0.081	0.277	0.130	0.040	0.237	0.267	0.024	0.047	0.049	0.034	0.010	0.010	0.016	0.024	0.195	0.8	1.0	0.8
BE 3	S2																				
WCB 1	S2	2.469	0.222	0.145	0.208	0.239	0.079	0.263	0.461	0.053	0.092	0.092	0.069	0.016	0.016	0.026	0.049	0.264	1.4	2.3	1.4
WCB 2	S2	1.027	0.087	0.050	0.230	0.098	0.073	0.117	0.197	0.124	0.034	0.038	0.030	0.010	0.010	0.018	0.014	0.141	0.6	0.7	0.4


COMB EFFIC FLAME
COMB EFFIC S1
COMB EFFIC S2
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
COMBUSTION EFFICIENCY
CAT
HEBO
MARIA 1
MARIA 2
DLAKE 1
DLAKE 2
BE 1
BE 2
BE 3
WCB 1
WCB 2
TEST AREA


PERCENT
0
20
40
60
80
100
120
140
160
180
PM 2.5
PM
Na
Al
Si
S
Cl
K
Ca
Ti
V
Cr
Mn
Fe
Ni
Cu
Zn
Br
Pb
Org C
El. C
Total C
SO 4
NO 3
NH 4
K/ FE
CL/ FE
EMISSION COMPONENT


CV *PERCENT*
200
150
100
50
0
K-CV
Fe-CV
K/Fe-CV
CV83 F
CV83 S1
CV83 S2
CV83 FIRE
CV84 F
CV84 S1
CV84 S2
CV84 FIRE
CV83-84 F
CV83-84 S1
CV83-84 S2
CVE3-84 FiRE
DATA BY YEAR


(PM-PM2.5)/PM2.5 INCREASES PROPORTIONAL
TO THE RATE OF ENERGY RELEASE.
DELTA PM
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
0
20
40
60
80
100
120
140
160
RATE OF ENERGY RELEASE (KW/M2)

CASE HISTORIES

1. WAYCROSS GEORGIA (WARD ET AL. 1979)

   A.) AIRBORNE (FLUX OF PM THROUGH VERTICAL PLANES AT SPECIFIED DISTANCES DIVIDED BY THE INVENTORIED MEASUREMENT OF FUEL CONSUMPTION.

   805 M Q = 253.1 G/S W = 13.08 KG/S EF_{PM} = 19.4 G/KG
   3360 M Q = 193.0 G/S W = 13.08 KG/S EF_{PM} = 14.8 G/KG
   7355 M Q = 255.8 G/S W = 13.08 KG/S EF_{PM} = 19.6 G/KG
   805 M Q = 236.2 G/S W = 14.55 KG/S EF_{PM} = 16.2 G/KG

   B.) SURFACE TOWERS (CMB) EF_{PM} = 8.1 G/KG MASS FLUX EF_{PM} = 11.2 G/KG; (FLUX OF PM THROUGH VERTICAL PLANE DIVIDED BY THE SURFACE MEASUREMENT OF FUEL CONSUMPTION.)

   C.) CCN PARTICLE SIZE DISTRIBUTION OVER DISTANCE. VOLUME FLUX METHOD. RELATIVE HUMIDITY VARIED FROM 65% TO 98 %. THE PARTICLE SIZE DISTRIBUTION CHANGED AS THE PLUME MOVED DOWNWIND. MASS FLUX OF THE PM AS DETERMINED USING THE INTEGRATING NEPHELOMETER REMAINED FAIRLY CONSTANT FOR THE THREE TRAVERSES. THE PM FLUX AS DETERMINED USING THE CN DATA DROPPED OFF RAPIDLY. THE TOTAL NUMBER OF PARTICLES MOVING DOWNSTREAM DECREASED BY A FACTOR OF 2.6, BUT THERE WAS AN INCREASE IN THE NUMBER OF PARTICLES BETWEEN 0.3 AND 0.5 µM. THE NUMBER OF PARTICLES BETWEEN 0.5 AND 10 µM DECREASED. A CONSTANT RESPONSE FROM THE INTEGRATING NEPHELOMETER WHILE THE TOTAL NUMBER OF PARTICLES DECREASED SUPPORTS THE IDEA OF PARTICLE COAGULATION IN TRANSIT. IN EFFECT, THE INCREASED SCATTERING EFFICIENCY DUE TO THE PARTICLES ACCUMULATING IN THE 0.3 TO 0.5-µM SIZE RANGE IS THOUGHT TO OFFSET THE LOSS OF SCATTERING BY THE GREATER NUMBER OF SMALL DIAMETER PARTICLES OBSERVED FOR THE 805-M CROSS SECTION.

2. GREEN MOUNTAIN OREGON (WARD ET AL. 1982)

   A.) EMISSIONS FLUX FROM AIRBORNE SAMPLES
   (PM: 526, 637, 417, AND 767 G/S)

   B.) RATE OF FUEL CONSUMPTION FROM GROUND MEASUREMENTS.
   (W: 28.1, 23.4, 20.5, AND 41.2 KG/S)

   C.) EF_{PM} VALUES FROM AIRBORNE SAMPLES.
   (EF_{PM}: 18.7, 27.2, 20.3, AND 18.6 G/KG).

   D) SURFACE BASED CMB METHOD FOR DETERMINING EF_{PM} VALUES.
   ($EF_{PM[F]}$: 12.0 G/KG, $EF_{PM[S]}$: 21 G/KG AND 28.5 G/KG,
   $EF_{PM} = 0.5*EF_{PM[F]} + 0.5*EF_{PM[S]} = 20.3$ G/KG.)

3. JOULE OREGON (RADKE ET AL. 1986, WARD 1986)

4. WEYERHAEUSER (WASHINGTON) FS (RADKE ET AL. 1986, WARD AND SANDBERG 1986)

5. WEYERHAEUSER (WASHINGTON) U. OF W. (STITH ET AL. 1981)

   A.) PARTICLE VOLUME DISTRIBUTION PEAKED AT 0.3 µM

   B.) EF_{PM} = 0.2 TO 2.0%.

   C.) THE BURNS WITH THE HIGHEST RATES OF FUEL CONSUMPTION HAD THE HIGHEST DENSITY.

   D.) LARGE SOURCE OF CCN; $\geq 10^{10}$ TO 10^{11} CCN WERE *PRODUCED* PER GRAM OF WOOD CONSUMED. THEY PRODUCE UNUSUALLY HIGH CONCENTRATIONS OF SMALL DROPLETS (< 10µM DIAMETER).

   E.) LARGE REDUCTION ON VISIBILITY (IN ONE PLUME THE VISUAL RANGE WAS 3% OF THAT IN CLEAN AIR).

6. AUSTRALIA (EVANS ET AL. 1976)

   A.) THE PARTICULATE MATTER YIELD FROM A HOT CLEARING BURN WAS REPORTED TO BE .44%

   B.) THE PARTICULATE MATTER YIELD FROM A FUEL REDUCTION BURN WAS 2% TO 4%.

   C.) THE PHOTOCHEMICALLY REACTIVE SPECIES MAY BE 5 TIMES MORE CONCENTRATED IN THE HOT CLEARING BURN THAN IN THE FUEL REDUCTION BURN.

   D.) THE HOTTER THE FIRE THE LARGER THE PRODUCTION OF NITROGEN OXIDES. ALL OF THE AUSTRALIAN FIRES WERE LOW INTENSITY BURNS.

RESEARCH NEEDS FOR SOURCE FUNCTIONS

A. TO COMPARE AIRBORNE MEASUREMENTS WITH SURFACE-BASED MEASUREMENTS FOR HIGHER INTENSITY FIRES (LOTI CANYON, CHABLEAU TYPE FIRES).

B. TO COMPARE MEASUREMENTS OF EMISSIONS FROM POOL FIRES USING EQUIPMENT FOR MEASURING EMISSIONS FROM FOREST AND RANGE FIRES.

C. TO MEASURE EMISSIONS FROM FIRES OF RUBBLEIZED MATERIALS FROM URBAN ENVIRONMENTS WITH EQUIPMENT USED FOR MEASURING EMISSIONS FROM FOREST AND RANGE FIRES.

D. TO ASSESS FACTORS CONTRIBUTING TO GRAPHYTIC CARBON PRODUCTION FROM FIRST CHEMICAL AND PHYSICAL PRINCIPLES AND FROM EMPIRICAL DATA FOR A WIDER RANGE OF FIRE AND FUEL CONDITIONS.

E. TO EXAMININE IN MORE DETAIL THE PHOTOCHEMICALLY ACTIVE SPECIES OF EMISSIONS PRODUCED FROM OPEN FIRES AND THE EFFECT OF HIGHER INTENSITY COMBUSTION CONDITIONS ON THESE EMISSIONS.

F. TO MEASURE EMISSIONS FROM A WIDER RANGE OF MASS IGNITED PRESCRIBED FIRES.

G. TO COMPLETE AN EMISSIONS CHARACTERIZATION DATABASE OF EXISTING EMISSIONS DATA.

THE FATE OF WILDFIRE SMOKE

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Smoke from the Great Borneo Fire convection columns behaved in two ways. Under stable, dry conditions they merged and spread large distances laterally. When there was sufficient moisture for condensation, they remained more seperated and formed vigorous cumulo-form clouds. This dichotomy gives a basis for forming statistical-alternative hypothesis for observed atmospheric temperature anomolies.

Statistical analysis shows a strong heating pulse in the troposphere in the smokey regions, while strong cooling occured in the lower stratosphere. The alternative postulate for the cooling pattern is based upon past experiments. They indicate that there are two kinds of smoke particles. The most common is a hydrophylic mixture of water, sugars and other soluables from pyrolysis. Rarer are the hydrophobic particles, which are made up of oily, surface acti... ...erials which are probably associated with carbon particles.

The hydrophylic par... ...es participate in the usual cloud processes. Hydrophobic ... ...cles "bounce" off precipitation, do not participate in nucle... ...processes and probably are carried to high altitudes by co... ...tive clouds. Hydrophylic particles carried to these altitude... ...l lose their water by evaportaion. In both cases a layer of ... ...tively active sub-micron particles will be left in the strat... ...re.

Analysis of Aerosols from Hiroshima Black Rain

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ABSTRACT

We have obtained samples of aerosols deposited during the Hiroshima fire storm that was initiated by the atomic bomb detonated on August 6, 1945. These particles, which we extracted from streaks of "black rain" found on a plaster wall, are being studied to resolve uncertainties in several areas. Questions being considered include the following: What is the distribution of particle sizes, and what are the optical properties of these particles? How can these data further our understanding of nuclear winter effects? Can examination of the shape, polymorphism, and chemical composition of these particles provide information about burning and particle generation during fire storms? Can examination of residual radionuclides in the particles and measurement of thermoluminescence in the plaster wall yield data that permit calculation of the skin dose to individuals who were directly exposed to the black rain?

Initial studies confirm that the artifact appears to contain aerosol particles that we believe are representative of the aerosols that may lead to a nuclear winter. Gamma spectroscopy measurements indicate the presence of naturally-occuring radionuclides K-40, Ra-226, Ra-228, Th-232, and Th-234, along with the fission product, Cs-137. Sooty particles of varying sizes down to the sub-micron size range have been detected using optical photomicrography. We have examined the particles using X-ray induced X-ray fluorescence and have detected Ca, Sr, Ba, Fe, and Zn, with elemental composition ratios representative of Hiroshima soil. Particle composition and size studies using electron and optical microscopy, LASER-flow cytometry, and electron-induced X-ray fluorescence are continuing, as is examination of the artifact using autoradiography and thermoluminescence.

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***Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

broadcast prescribed burns of logging slash in western Washington and western Oregon using the CMB method include emission factors for:

1.) Particulate matter by size class,
    a.) PM (4.2 to 34.2 g/kg),
    b.) PM2.5 (1.2 to 18.2 g/kg)
    c.) Light absorption properties
2.) Carbon content of PM2.5
    a.) elemental carbon (2.6% to 40.3%)
    b.) organic carbon (16.8% to 62.6%)
    c.) total carbon (38.7% to 65.2%)
3.) Gases (CH_3Cl, COS, NO_2, CO, CH_4, CO_2, and others)
    a.) CH_3Cl (.004 to .052 g/kg)
    b.) CO (28.3 to 459.6 g/kg)
    c.) CH_4 (0.7 to 10.6 g/kg)
    d.) CO_2 (1014.1 to 1781.4 g/kg)
4.) Polynuclear organic materials (B[a]P)
    a.) B[a]P (18.8 to 398.3 5g/kg)
    b.) Total PAH fraction (0.88 to 14.11 mg/kg)
5.) Aldehydes, organic acids, and others.
    a.) Acetaldehyde (.08 to 14.13 g/kg)
    b.) Furfuraldehyde (.03 to 2.09 g/kg)

We have proposed making measurements of most of the above emissions for a series of fires (4 to 6 separate fires) of chaparral fuels similar to the fuel that will be burned during the large-scale experiment at the San Dimas Experimental Forest. The objectives for this research are:

1.) To measure emission factors for the above emissions.
2.) To compare these emission factors by major fuel type with the results for the larger experiment.
3.) To project for the larger fire the effect of the fuel and fire variability on the source characteristics of emissions sampled by the airborne systems.
4.) To test for similarity of source characteristics between airborne and surface measured emissions.

AIRBORNE LIDAR CHARACTERIZATION OF OPTICAL AND PHYSICAL PROPERTIES OF NUCLEAR INDUCED ATMOSPHERIC EVENTS

Edward E. Uthe
Warren B. Johnson
SRI International
Menlo Park, Ca. 94025

ABSTRACT

Experimental data are needed for the development and validation of climatic models to predict the consequence of atmospheric events triggered by a nuclear conflict. A series of field tests are planned to acquire this necessary data in the presence of large scale smoke and dust events. We believe that airborne lidar observations can provide information on the temporal and spatial distribution of particulate backscatter and extinction coefficients that can not be obtained by other means. Path-integrated extinction (transmission) data for dense aerosol distributions can be derived from ground-reflected lidar signatures. Smoke and dust cloud transport and diffusion parameters can be derived from observed geometric distributions of enhanced scattering volumes. On-board radiometric sensors can supplement the lidar observations in evaluating smoke and dust properties, and the density of intervening atmospheric elements such as high-altitude cirrus clouds.

This paper presents data examples from previous studies that demonstrate the capabilities of lidar, and proposes a methodology for the use of airborne lidar on future field studies.

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AIRBORNE LIDAR CHARACTERIZATION OF OPTICAL AND PHYSICAL PROPERTIES OF NUCLEAR-INDUCED ATMOSPHERIC EVENTS

Edward E. Uthe
Warren B. Johnson

SRI International
Menlo Park, CA 94025
415/859-4667

This paper presents data examples from previous field experiments that demonstrate expected capabilities of airborne lidar for evaluating smoke and dust source terms over large regional areas. A bibliography of recent published results is included.

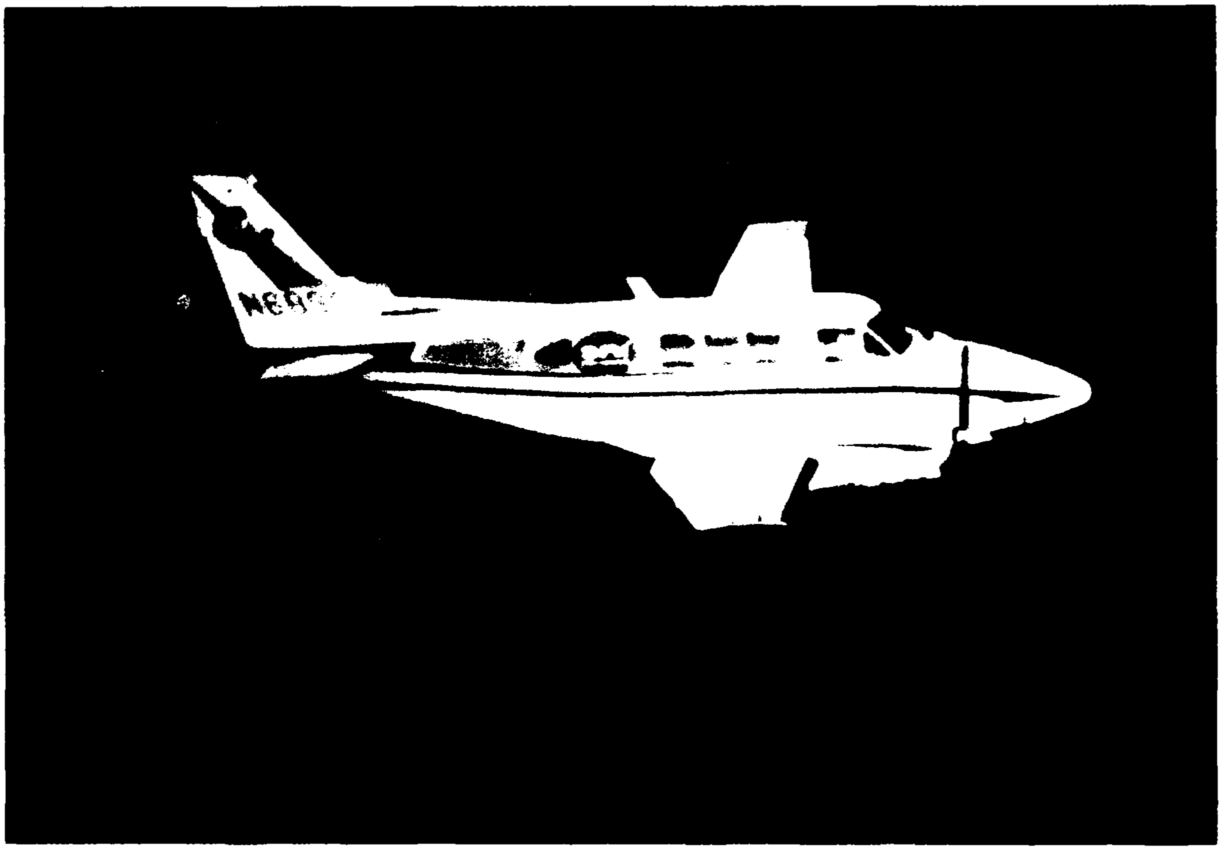
SRI INTERNATIONAL LIDAR SYSTEMS

GROUND MOBILE

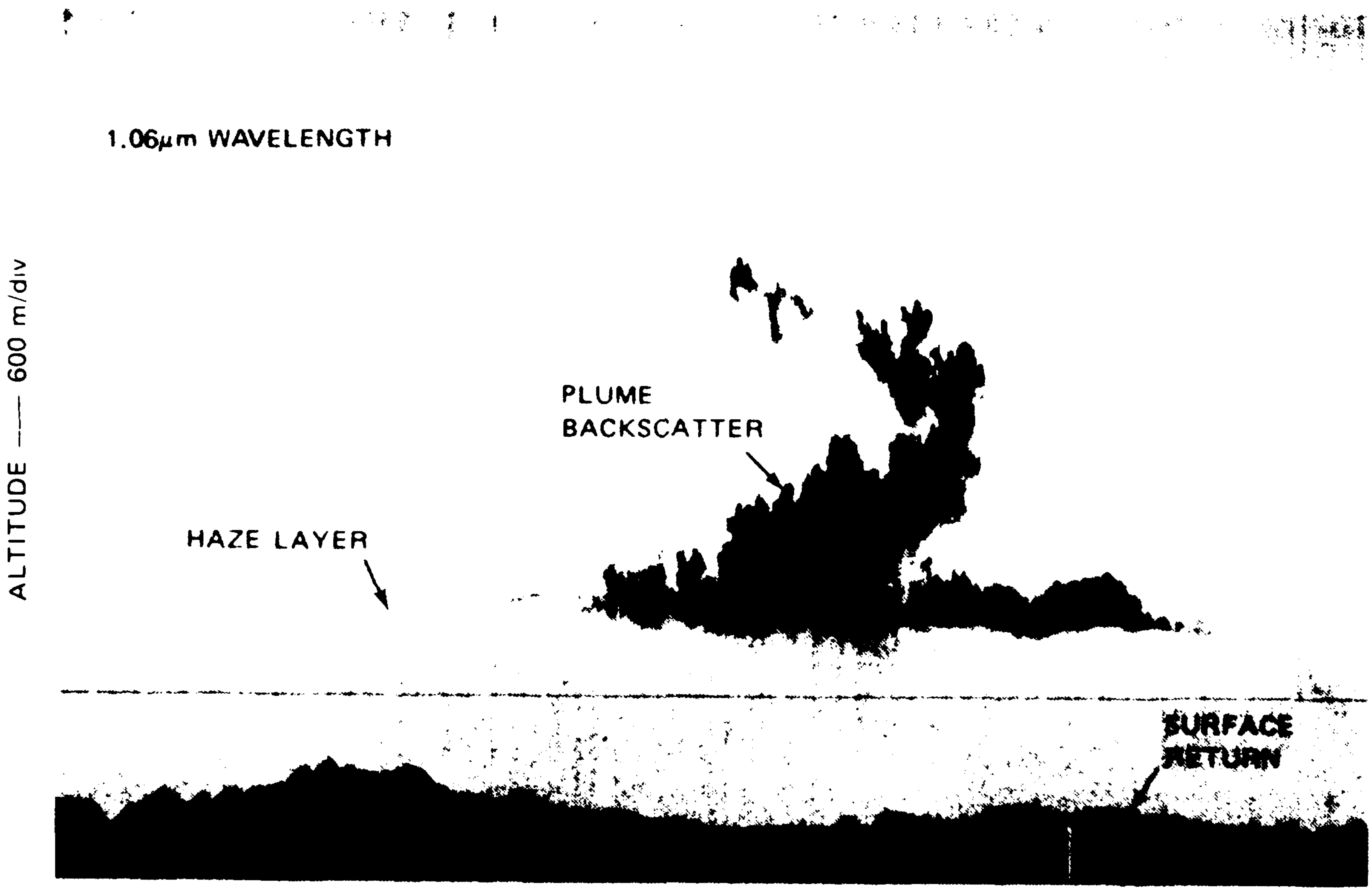
• MARK IX	0.69 μm
• 4–λ	0.53, 1.06, 3.8, 10.6 μm
• UV DIAL	UV (2)
• IR DIAL	9.5–11 μm (4)
• NEAR IR DIAL	3–4 μm (2)

AIRBORNE

• ALPHA-1	0.53, 1.06 μm
• ALPHA-2	0.53, 1.06 μm
• ALARM	9.5–11 μm (2)



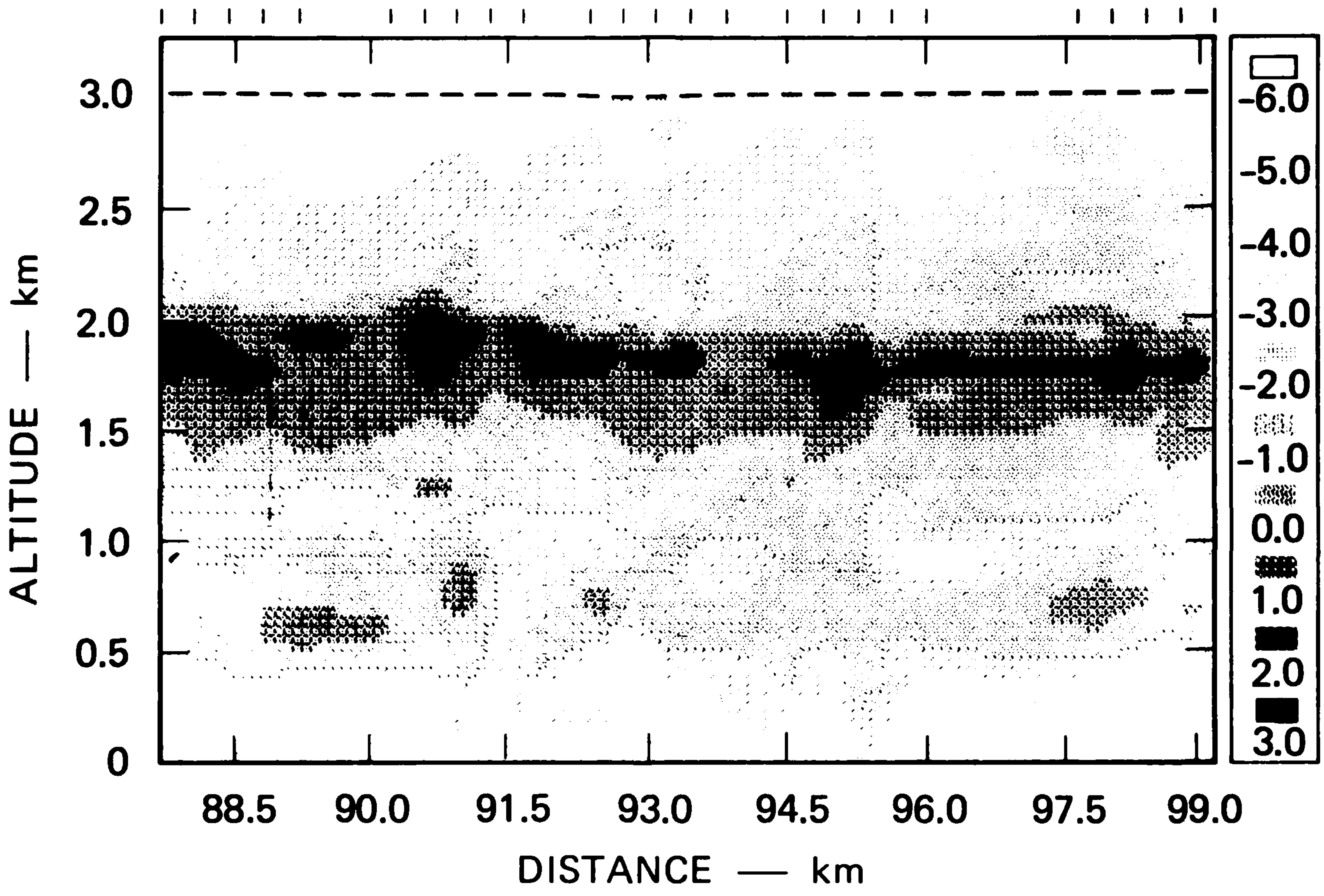
SRI LIDAR AIRCRAFT



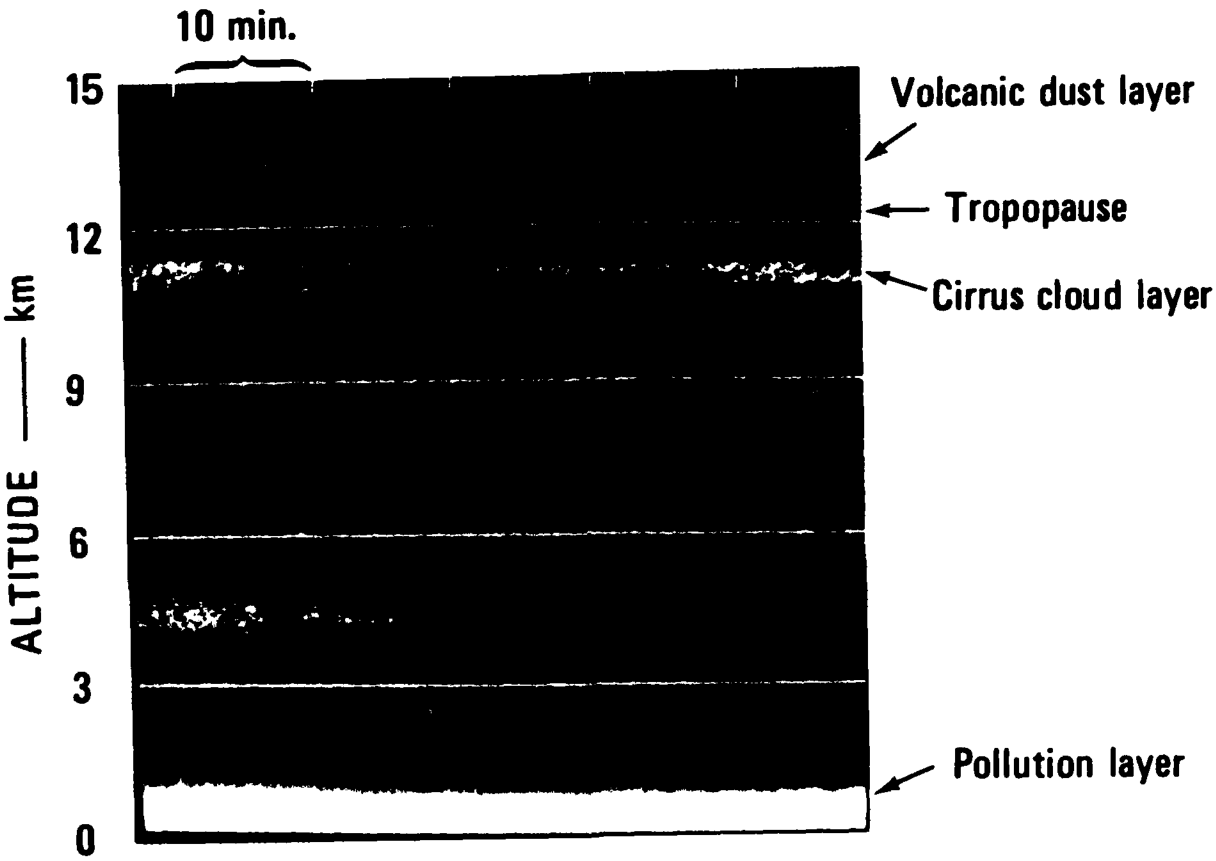
CROSS-PLUME STRUCTURE DERIVED FROM ALPHA-1
PLUME BACKSCATTER AT 1.06-μm

AIRBORNE LIDAR OBSERVATION OF AN AEROSOL PLUME GENERATED FROM AGRICULTURAL BURNING (Clear-Air Near-Surface Aerosol; Layer Height is Seen To Conform To Terrain Heights)

AIRBORNE LIDAR MAPPING OF SAHARA DUST LAYER OVER CARIBBEAN REGION
(1969 BOMEX PROJECT)



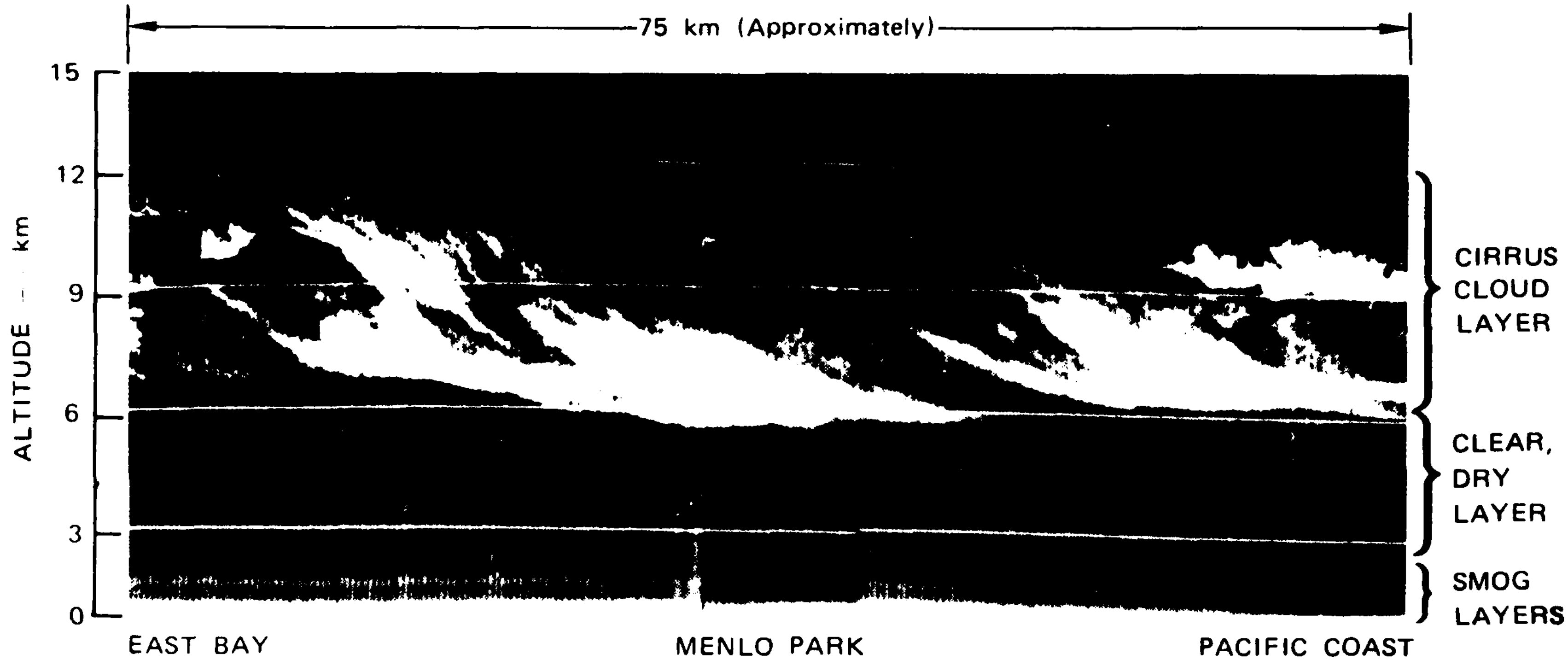
DEVIATIONS FROM BEST FIT
EXPONENTIAL ATMOSPHERE, Relative DB Units



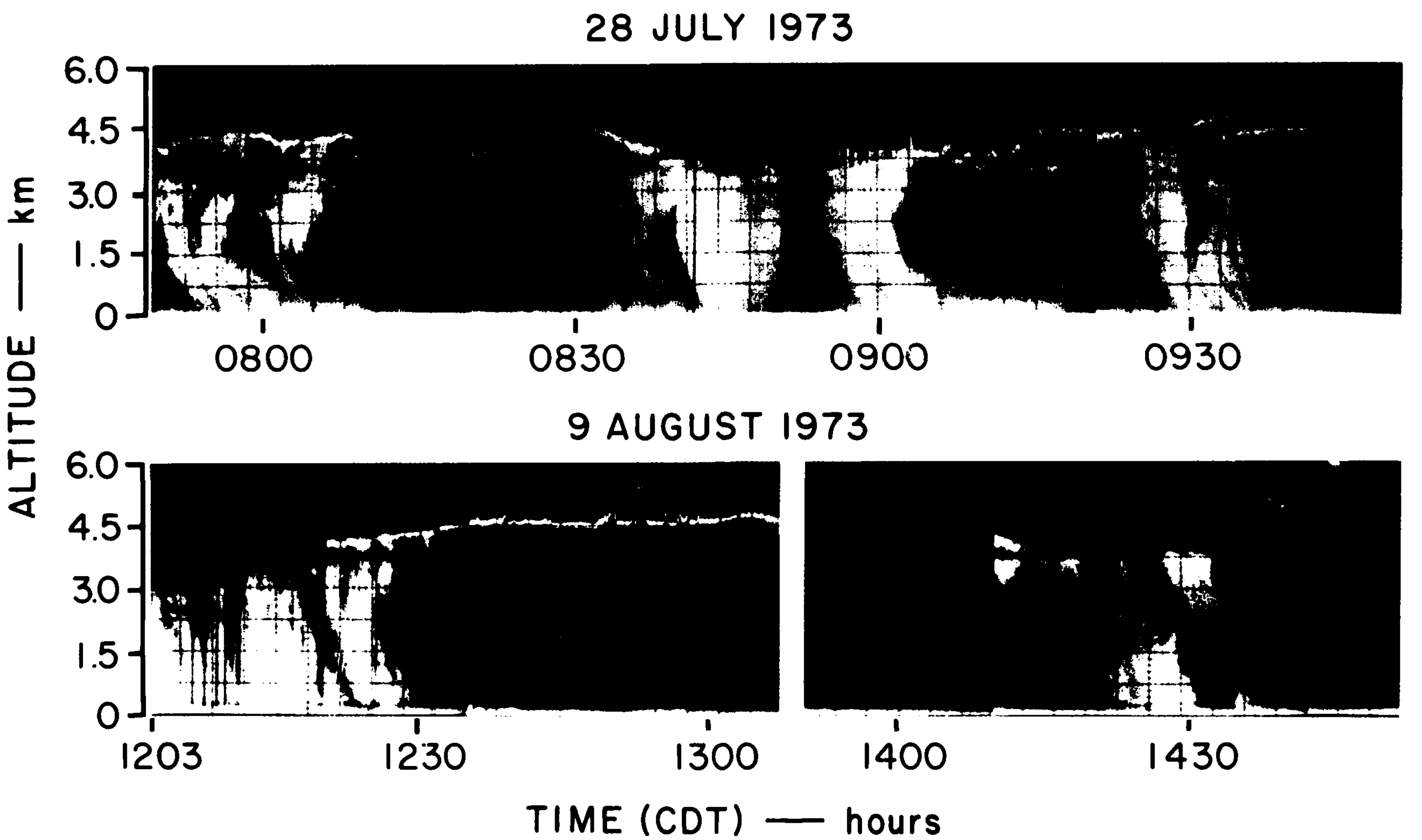
SRI MARK IX LIDAR OBSERVATIONS
OF MT. ST. HELEN'S AEROSOL LAYER
Menlo Park, California, 2 June 1980

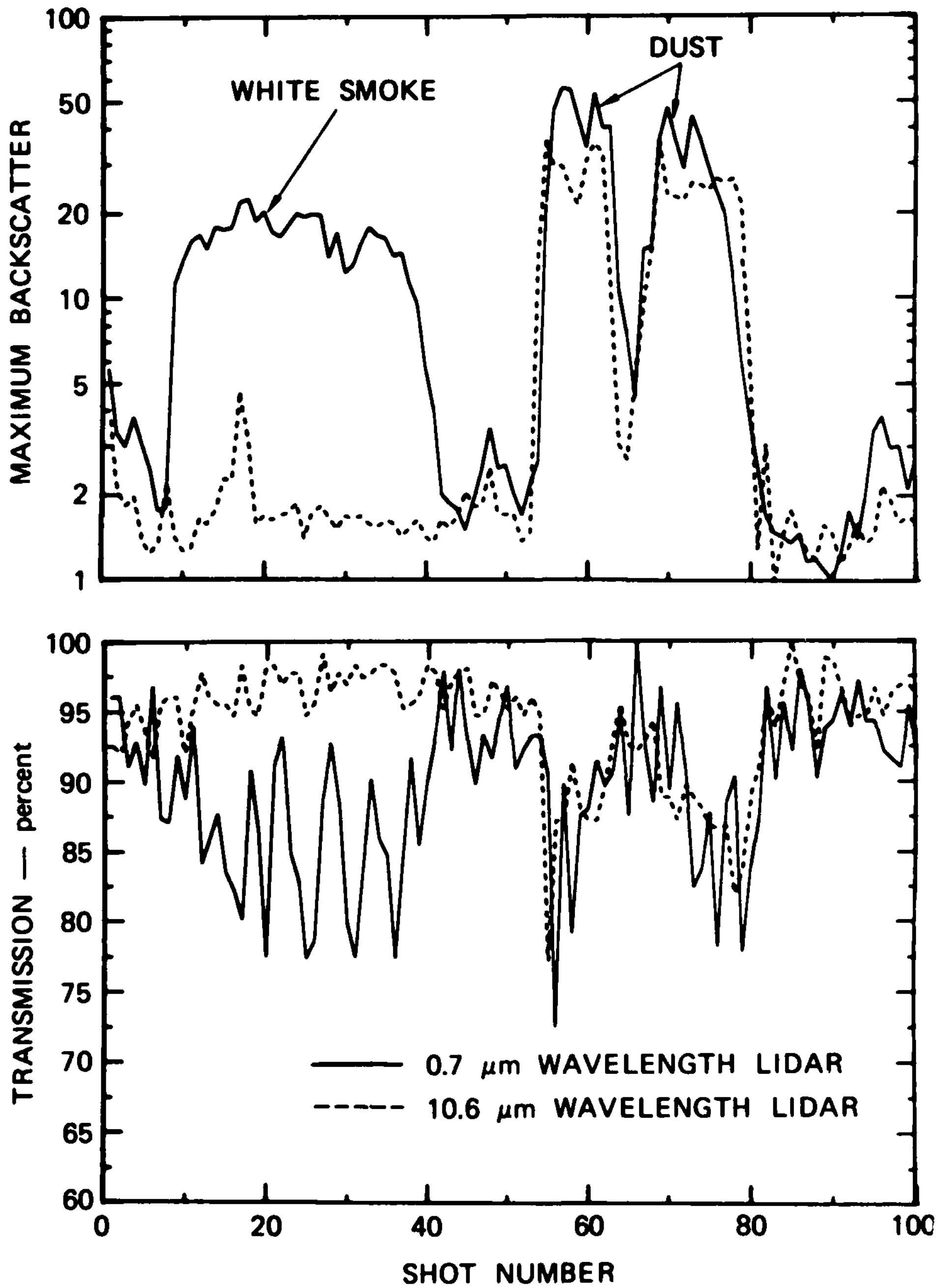
LIDAR-OBSERVED CIRRUS CLOUD STRUCTURE, MENLO PARK, CALIFORNIA

23 JANUARY 1976, 1000-1200 PST

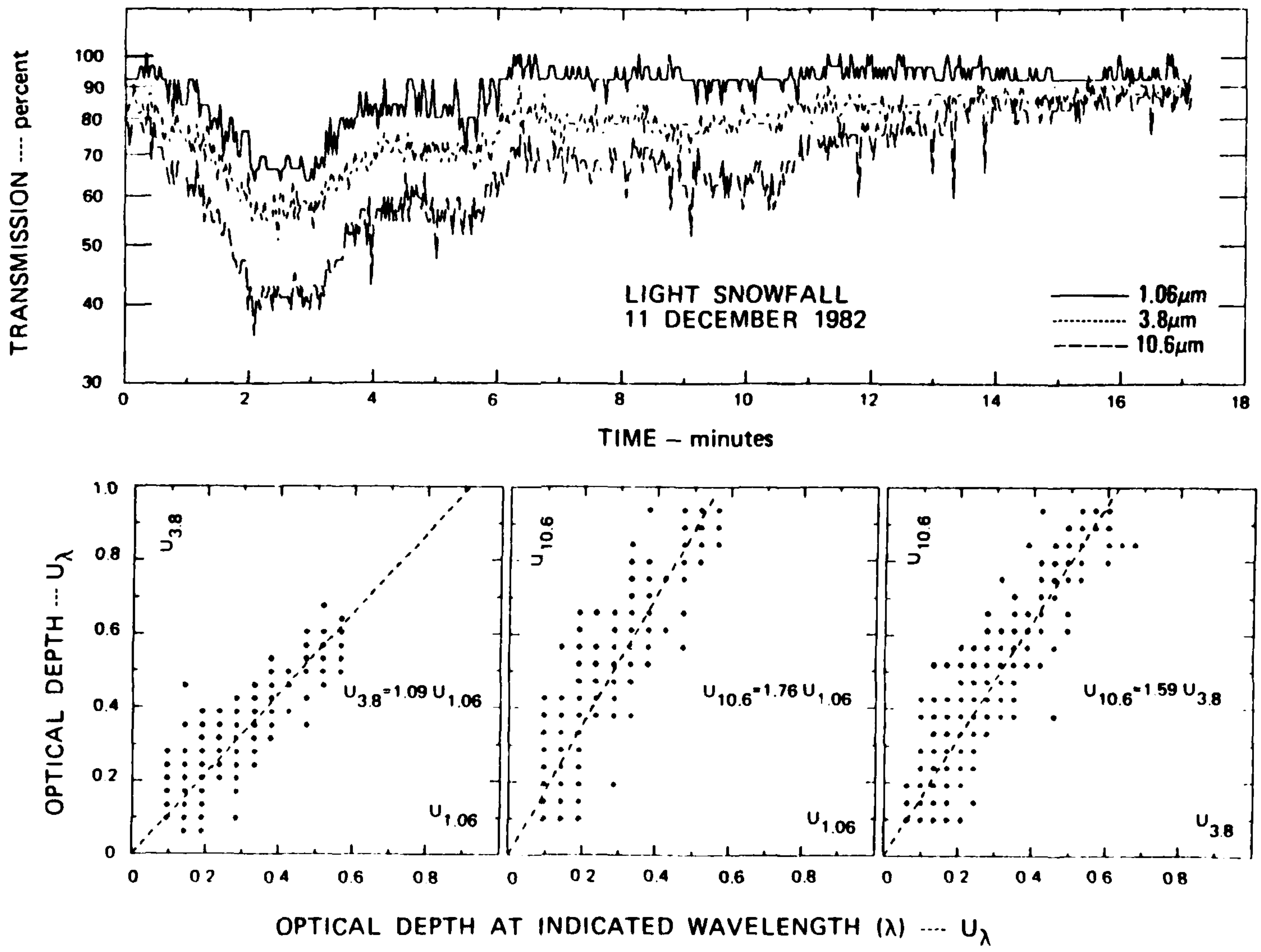


UPWARD VIEWING LIDAR OBSERVATIONS OF RAINFALL (ST. LOUIS, MO.)

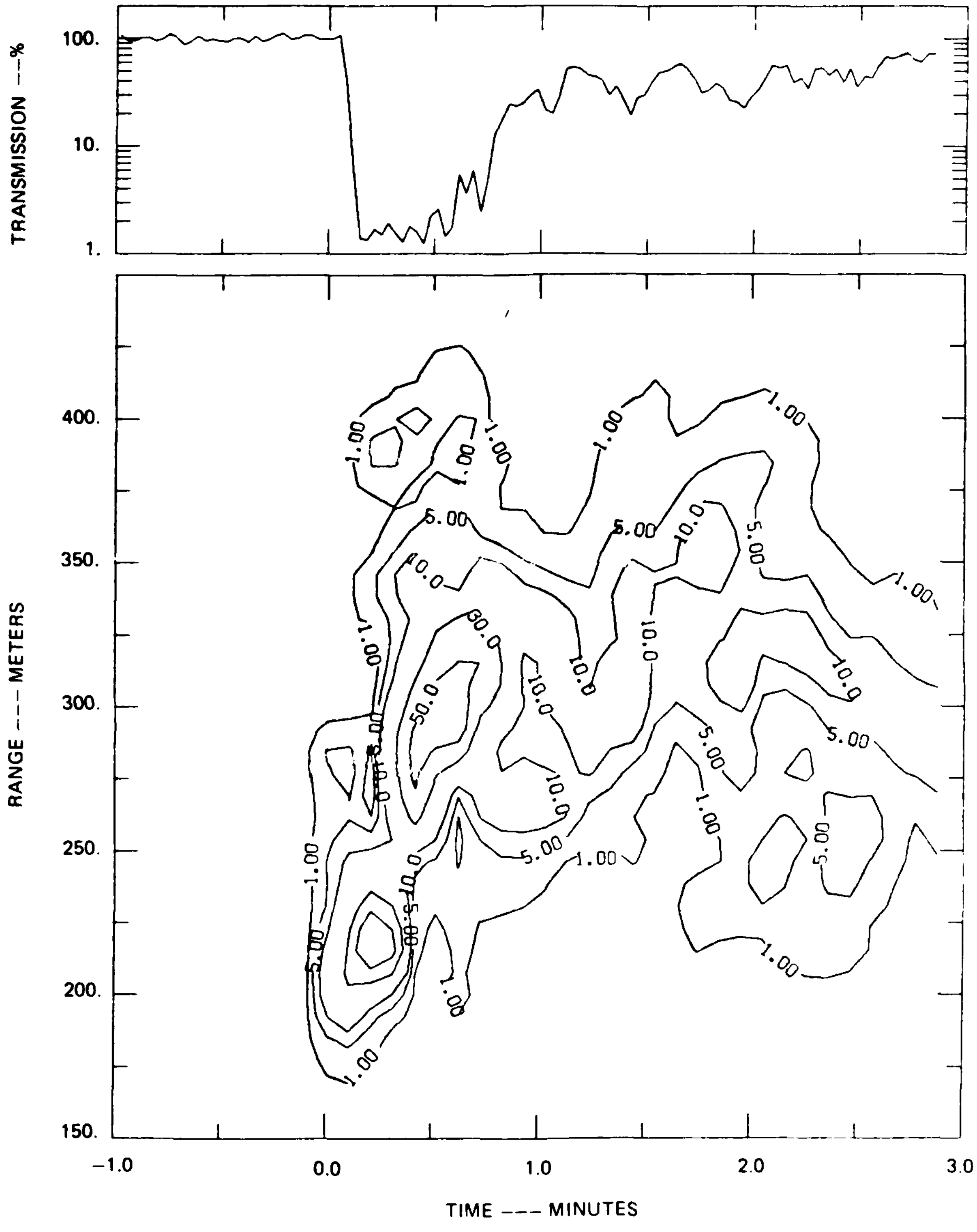




Transmission and maximum backscatter observed by the two-wavelength lidar system for road dust and white smoke. Backscatter is relative to clear-air backscatter. Transmission has been normalized to 100% for clear air.

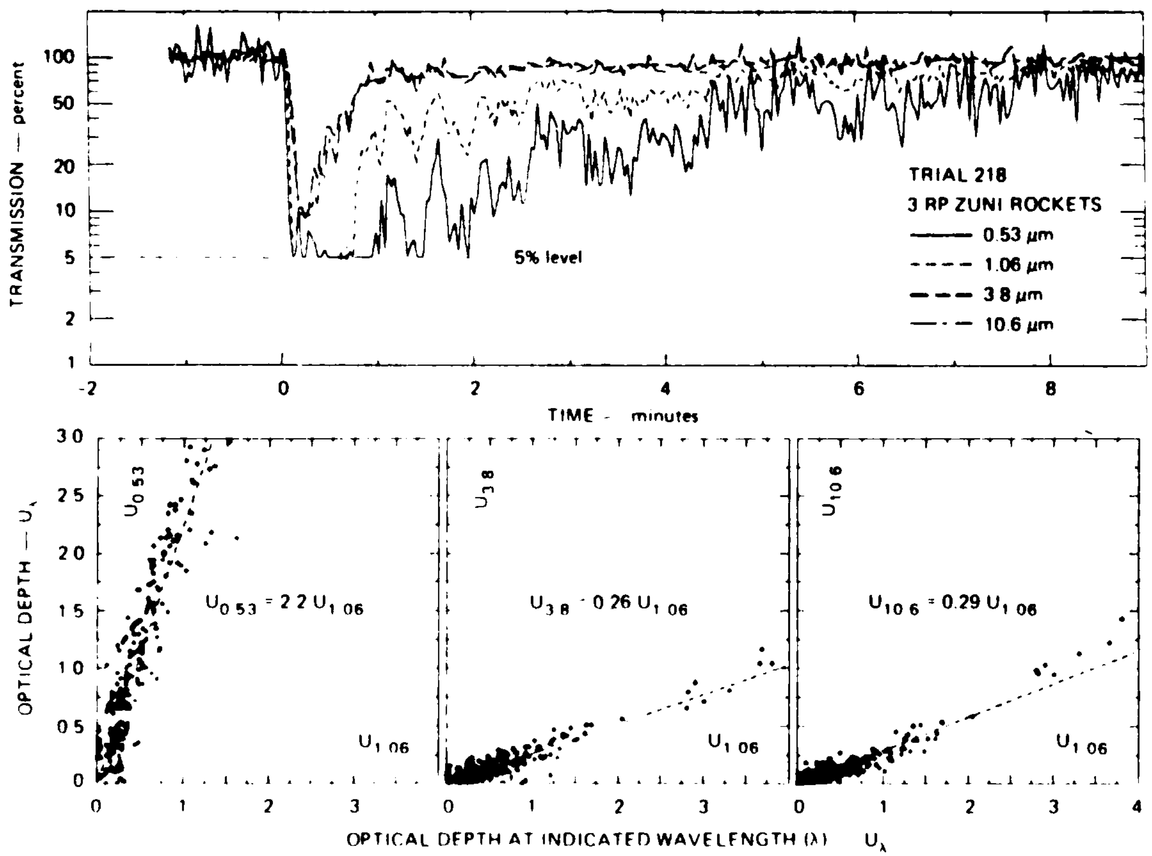


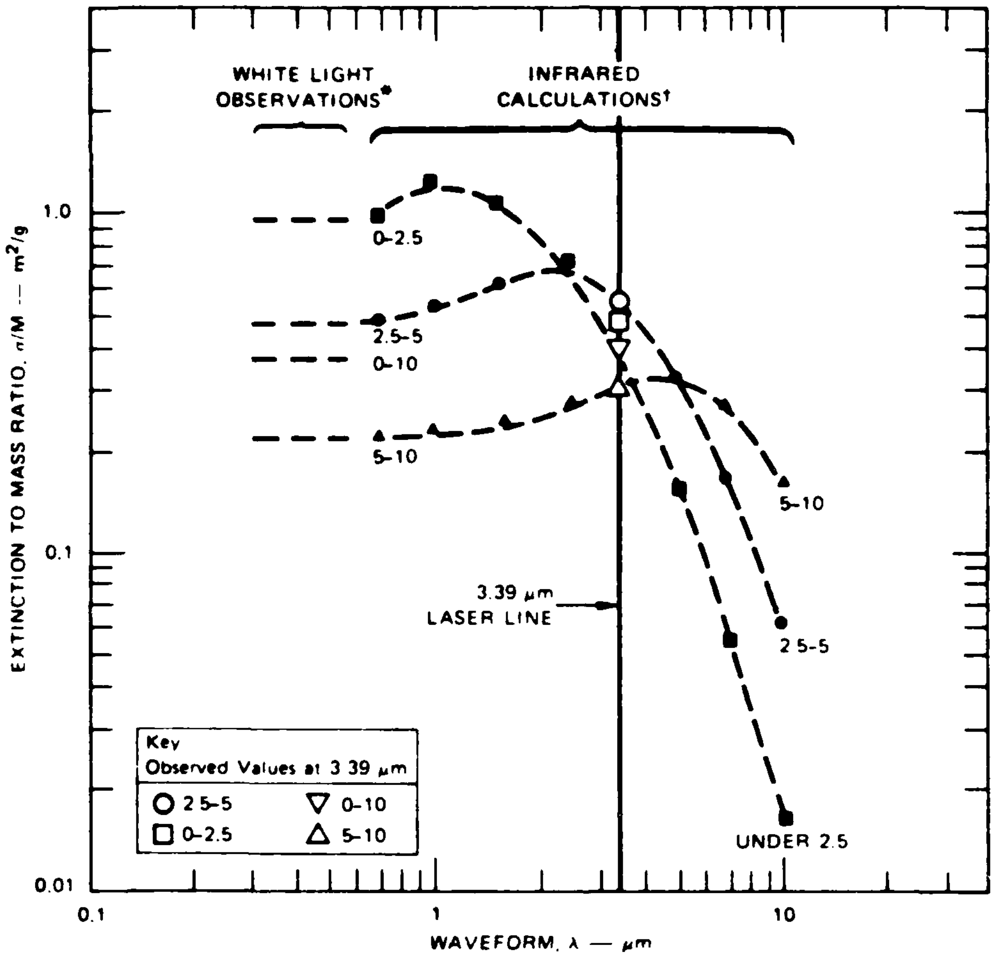
TRANSMISSION HISTORY AND OPTICAL DEPTH RELATIONSHIPS FOR LIGHT SNOWFALL



CONTOUR MAP OF 1.06 μm WAVELENGTH EXTINCTION COEFFICIENT (km^{-1}) DISTRIBUTION ALONG THE LIDAR OPTICAL PATH AS A FUNCTION OF SMOKE EVENT TIME. CORRESPONDING TRANSMISSION HISTORY IS PLOTTED ABOVE THE CONTOUR MAP.

TRANSMISSION HISTORY AND OPTICAL DEPTH RELATIONSHIPS FOR SMOKE (ZUNI ROCKETS)



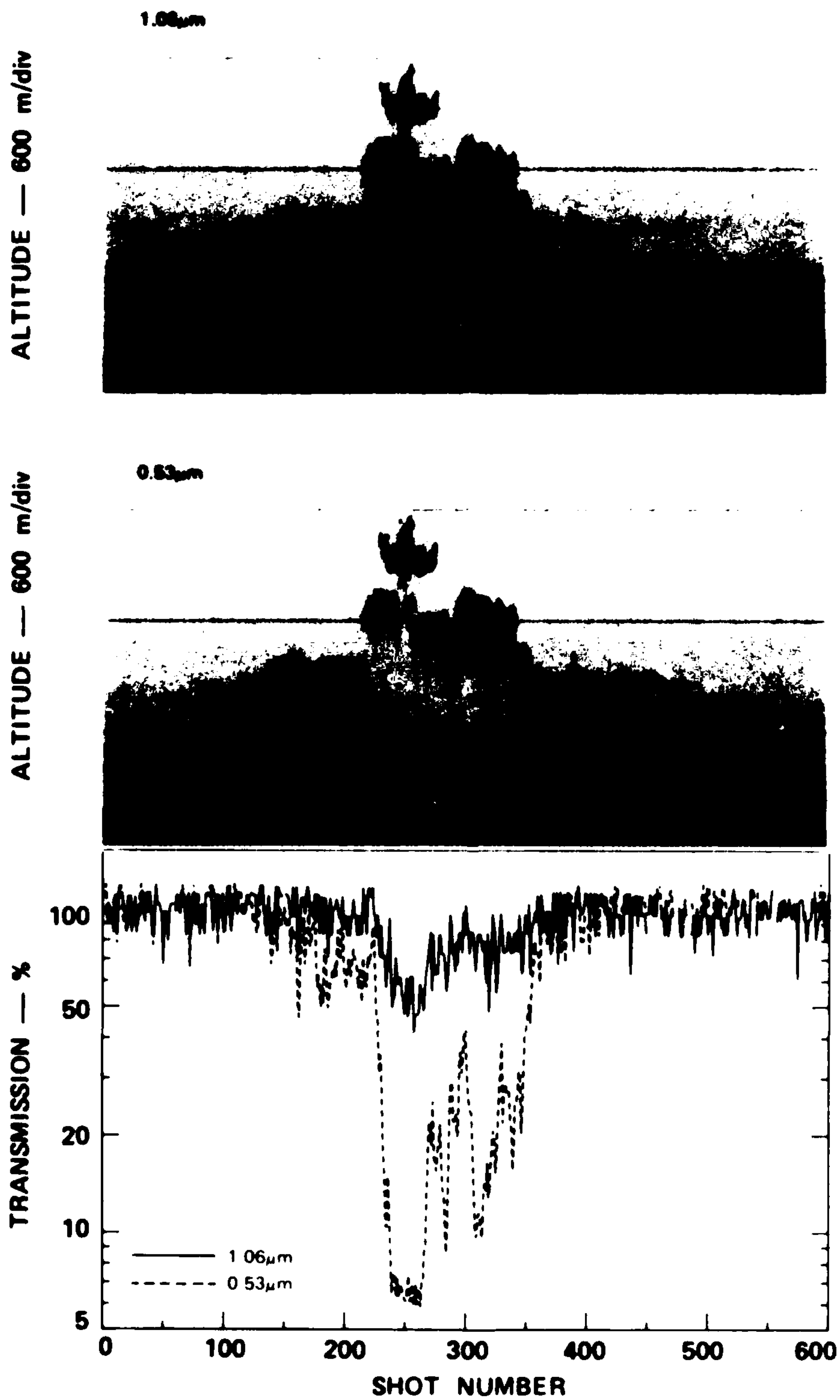


*Values measured by Uthe and Lapple for fly ash aerosols with 0-2.5, 2.5-5, 5-10, and 0-10 μm diameter size fractions

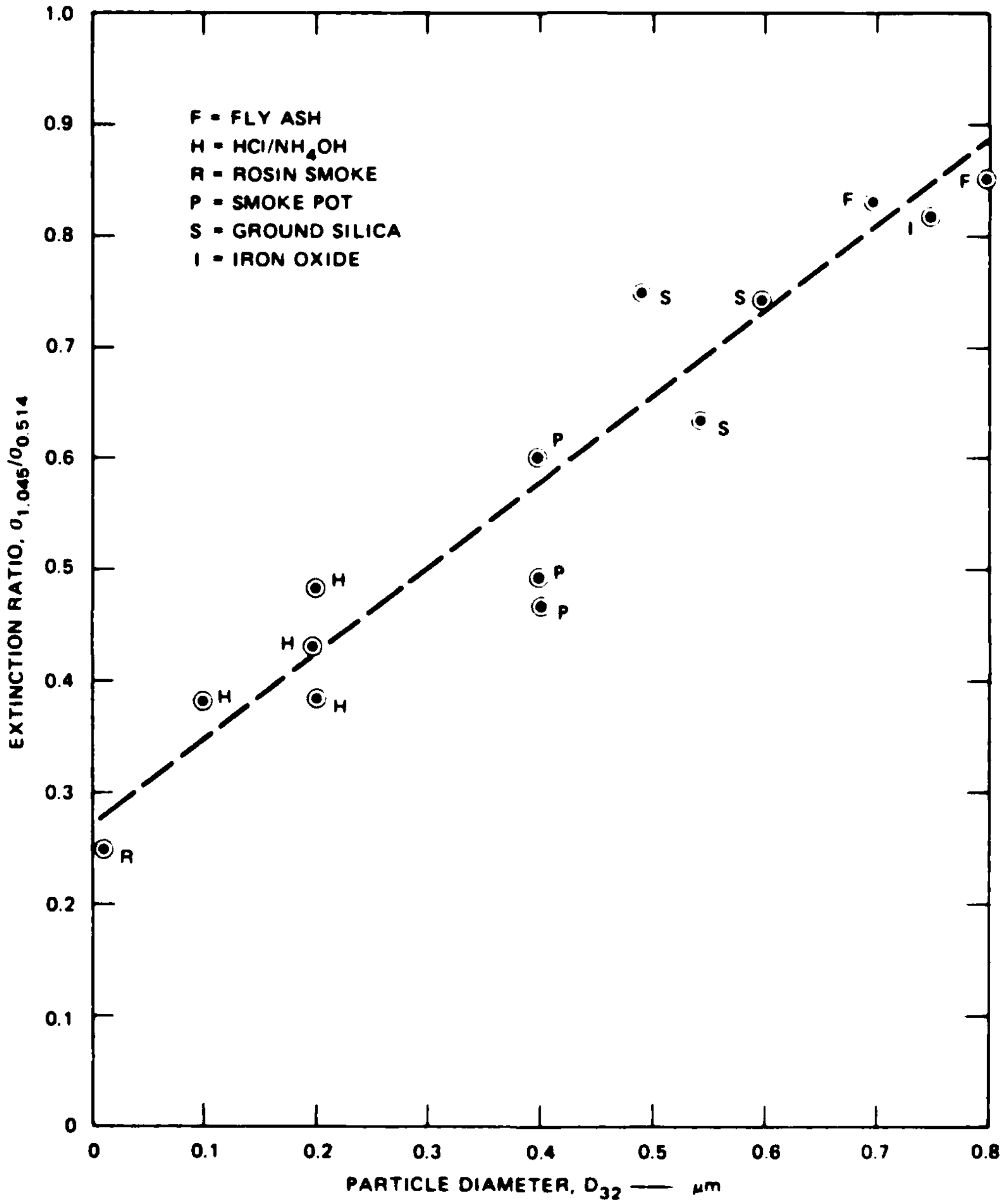
†Based on log normal size distributions fitted to measured fly ash size distributions.

THEORETICAL AND OBSERVED DEPENDENCE OF THE EXTINCTION-TO-MASS RATIO OF FLY ASH AEROSOLS ON PARTICLE SIZE AND WAVELENGTH OF THE LIGHT SOURCE

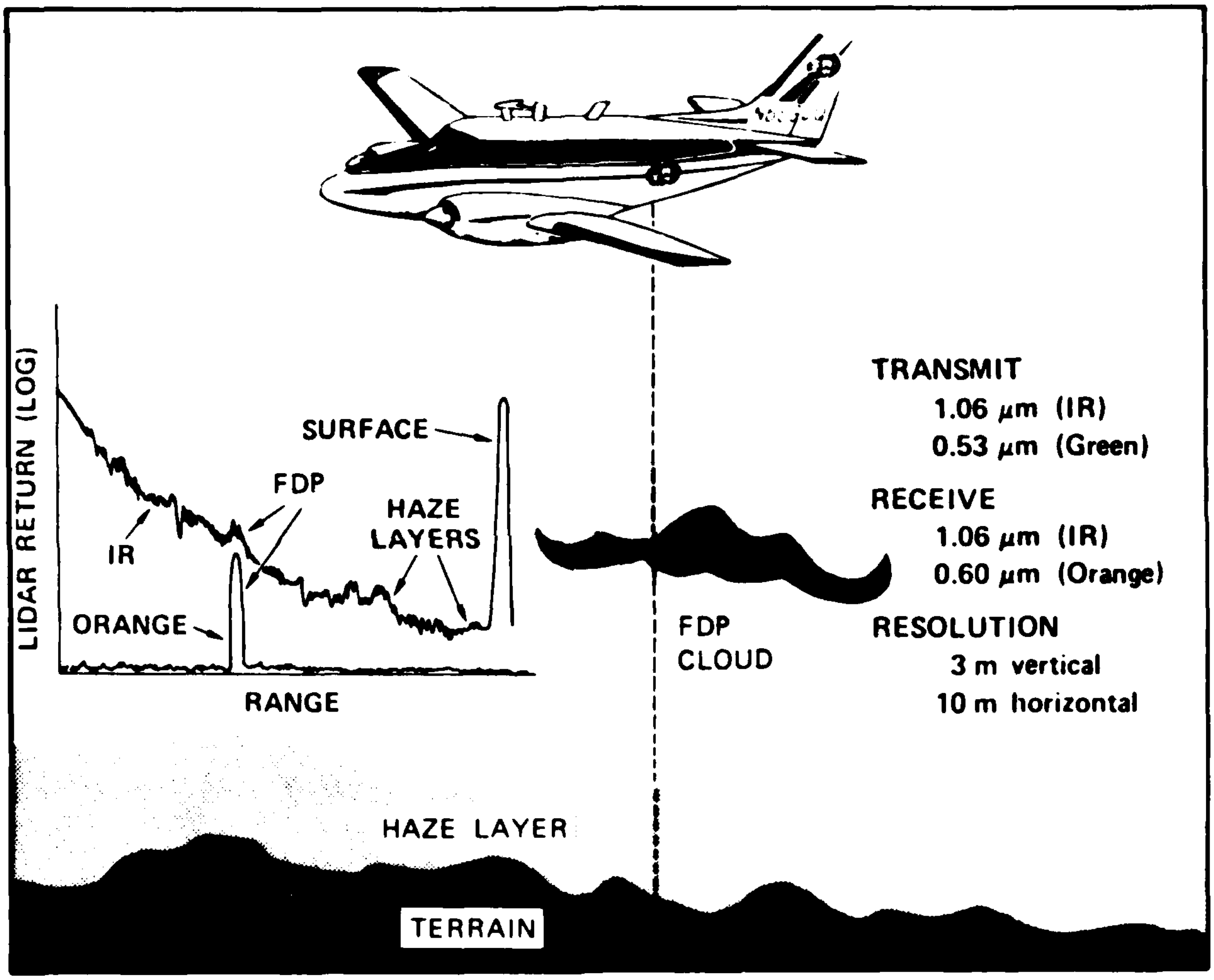
CROSS-PLUME STRUCTURE DERIVED FROM ALPHA-1 PLUME BACKSCATTER AND VERTICAL TRANSMISSIONS DERIVED FROM SURFACE RETURNS AT 1.06- AND 0.53μm WAVELENGTHS



RELATIONSHIP OF EXTINCTION RATIO AT WAVELENGTHS OF 1.045- AND 0.514-μm AND MEAN PARTICLE DIAMETER DERIVED FROM LABORATORY RESULTS[4]



RELATIONSHIP OF EXTINCTION RATIO AT WAVELENGTHS OF 1.045- AND 0.514-μm AND MEAN PARTICLE DIAMETER DERIVED FROM LABORATORY RESULTS[4]



ALPHA-1 FLUORESCENT DYE PARTICLE (FDP) TECHNIQUE

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An airborne, autotracking, external-head sunphotometer for plume studies.

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An airborne, automatically sun-tracking sunphotometer consisting of a detector module, temperatrure control system, nitrogen purge system, mechanical drive chain and data collection system has been developed. The instrument measures continuously vertical profiles of optical depth and transmissivity. The detector head is mounted outside the aircraft cabin to maximize sun-viewing opportunities and to avoid viewing through a cabin window at varying transmission angles. Using 6 separate detectors, each with its own optical filter, rather than a single detector with a filter wheel, measurements at 6 different wavelengths from 0.38 to 1.02 um can be taken simultaneously to investigate plumes of even limited extent at aircraft speeds as high as 100 m/sec.

The data collection system consists of a multiplexer, 12-bit analog-to-digital converter, aircraft data interface electronics, and a Hewlett-Packard HP9816 computer with a floppy disk and a printer. The sampling period is synchronized to the aircraft data system that updates the navigation data approximately every 2 seconds. The 6 detector signals, detector temperature, pressure altitude, longitude, latitude, tracking error, sun tracker azimuth and elevation, and GMT are recorded on floppy disks and also printed out for data backup. The HP9816 is also used for postflight data processing and Langley and optical depth plots.

Mounting configurations for Convair C990 and C131, MacDonnel-Douglas DC8 and Lockheed C130 aircrafts have been developed or are being contemplated.

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SECTION 3

MISCELLANEOUS TOPICS

Biologically Important Issues for Research on the Physical Effects of Nuclear War

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Cornell University

* Endpoints of Concern - Human Effects
* Fallacy in Delaying Biological Analyses
* Uncertainties - Biological vs. Physical Issues
* Vulnerabilities Define Relevance of Research

Key Conclusions from SCOPE-ENUWAR Study

* Indirect Effects > Direct Effects
* Ecological Effects
  - Unprecedented in Extent and Intensity
  - Different Ecosystems with Different Vulnerabilities
  - Long-Term Recovery Prospects
* Natural Ecosystems - Human Carrying Capacity < 1% Global Population
* Agroecosystems Most Vulnerable to Disturbance
* Agricultural Effects
  - Temperature Most Important
    - Few degrees vice tens of degrees
    - Many mechanisms for temperature effects
  - Other Climatic Effects Also Important
  - If No Climatic Effects, Still Problem Human Subsidies
* Possibility of Elimination or Severe Disruption in Grain Production
  - for at least N.Hemisphere
  - for at least one growing season
* Food Limitations Critical
  - Stores Depleted Prior Next Growing Season
  - Stores Could Support Only Small Fraction of Global Population for 1Yr
* Other Effects
  - Radiation
    - global fallout - little effect
    - local fallout - large effect
  - UV-B - potentially large effect
  - Air Pollutants - potential local effects
  - Synergisms
* Societal Effects - little studied, potentially large effects

Mechanisms for Climatic Effects on Agriculture

* episodes of freezing during growing season
  - acute and chronic period
  - variance vs. average temperature
  - spatial extent
  - long-term reverberations
  - poorly estimated
* shortening of growing season
  - chronic period
  - variance vs. average temperatures
  - spatial extent
  - poorly estimated re nuclear war

  - historical records
  - statistical analyses
  - latitudinal gradients
* increase in growing season length requirements by crop
* insufficient thermal time
  - chronic period
  - average only
  - better estimates
* insufficient integrated insolation time
  - chronic period
  - average only
  - daylength
  - little attention
* suboptimal environmental conditions
  - temperature
  - light
  - precipitation ** key issue

Variance Issues

* Acute Period
    - spatial heterogeneity
    - temporal heterogeneity
    - extremes vs. averages

* Chronic Period
    - extremes vs. averages
    - variable vs. fixed growing season
    - diurnal range

Issues re Averages in Temperatures Over Time

* Uniform

1.) reduce daily averages
  - unknown effect re diurnal range
2.) reduce daily max, mins
  - no change in diurnal range
3.) reduce daily min, not max
  - increase diurnal range
4.) reduce daily max, not min
  - decrease diurnal range

*Non-Uniform

1.) increase frequency of cold events
2.) increase duration of cold events
3.) increase intensity of cold events

Research Needs Climatic Effects

Acute Period

* Rate of onset of temperature and light reductions
* Absolute temperatures vice decrements
* Spatial extent of freezing events
* Spatial and temporal heterogeneity
* Smaller scales - global/regional/local
* Daylength
* Light spectra
* Precipitation
* Seasonality of effects
* Variance issues

Research Needs Climatic Effects

Chronic Period

* Duration, intensity of temperature decreases
    - frost-free season duration
    - effects of seasonality
    - Southern Hemisphere effects
    - surface water effects
* Duration, intensity of light decreases
    - daylength
    - spectral quality
* Duration, intentity of precipitation decreases
    - coastal, orogenic effects
    - monsoon disruption
* Variance issues
    - spatial heterogeneity
    - average changes vs. variance changes
    - uniform vs. non-uniform
    - diurnal ranges
* Ocean/atmospheric interactions
    - coastal vs. continental effects
    - ocean currents
* Long-term feedbacks
    - albedo
    - Antarctic ice pack dynamics
    - greenhouse gases
    - biological feedbacks (e.g., fires, CO_2, hydrology, desertification)

Research Needs Other Effects

Radiation

* Distribution and levels of local fallout
    - variety of scenarios
    - spatial heterogeneity
    - increased emphasis Beta-emitters

* Internal doses
    - fate and transport
    - routes to humans post-war conditions
    - dose levels
    - gamma, Beta, and alpha-emitters

UV-B

* Increased levels expected
    - duration
    - spatial distribution - latitude/altitude
    - effects particulates on ozone layer

Air Pollutants

* Variety of pollutants
    - CO
    - pyrotoxins
    - ozone
    - asbestos
    - NOx
    - acid precipitation
    - hydrocarbons
    - others

* Levels expected
    - spatial distribution, extent
    - duration

DR. LEON GOURE
SAIC/MCLEAN, VA

SOVIET RESEARCH ON GLOBAL EFFECTS
(PAPER GIVEN AT THE DNA GLOBAL EFFECTS PROGRAM TECHNICAL MEETING, AMES RESEARCH CENTER, 25-27 FEBRUARY 1986)

There are obvious reasons for interest in Soviet research into the global effects and consequences of the nuclear war.

First, for some time now Soviet scientists have been active participants in the international scientific research efforts to study the global effects and consequences of a nuclear war. Indeed, it could be said that this has been a major area of at least apparent Soviet scientific cooperation with the international scientific community. Soviet scientists have also appeared as actors in the public debate in the Free World concerning the consequences and potential implications of the effects. While the participation of Soviet scientists in these studies has been generally welcomed by the international scientific community for scientific as well as political reasons, it is useful to assess the actual contribution which Soviet scientists have made in this field and the validity of their claims to have independently validated the key findings and projection of their western colleagues.

Second, as we all know, many issues concerning global effects are fraught with large uncertainties and are quite sensitive to assumptions, choices of scenarios, value judgements, etc. The Soviet Union has many highly qualified, indeed outstanding scientists who, one might expect, could make significant contributions from an independent, non-Western perspective on the basis of their own data and experiments to our understanding of the effects and their consequences.

Third, in principle, findings on the global effects could have important implications for the nuclear powers' defense policies, force level requirements, views on deterrence and strategic stability, targeting doctrines, weapons development programs, arms control, and so on, or in brief on the feasibility and risks of resort to nuclear weapons. It is important, therefore, to try to ascertain actual Soviet views on and degrees of real Soviet concern about the various possible global effects and their implications for Soviet war fighting doctrine and strategy. In this respect a distinction may have to be made between what the Soviets regard as serious problems and those which they seek to exploit for policy purposes. It is also obvious that asymmetries in East-West understanding and evaluations of the consequences of nuclear war could be dangerously destabilizing.

Fourth, it is inevitable that perceptions of or claims about various global effects and their consequences will be used for propaganda and political purposes. It is especially important to keep in mind that in the Soviet Union science and scientists are under the control of the state and that scientists are called upon by the party leadership to use their influence and prestige in support of the Soviet Union's propaganda and foreign policy objectives. This was clearly spelled out by Boris Ponomarev at the all-union conference of Soviet scientists held in Moscow in May 1983. One result of this is that the better known or publicized Soviet work on global effects in the West has been in a large measure deliberately targeted on Western audiences not just for scientific but also for political effects. Indeed, a significant part of this work is not published in the Soviet Union or appears only in publications specifically aimed at foreign audiences. This raises questions about the seriousness of Soviet scientific purposes in this field and Soviet objectives. At the same time, however, there is other Soviet work which is given less publicity abroad, but which may reflect more serious Soviet interests and concerns and which, therefore, may deserve more careful attention on our part.

Let me say, that as a "Sovietologist" or political scientist and not a physical scientist, I am only an observer of and not a direct participant in the scientific effort to study global effects of nuclear war. I have, however, a long-standing interest in studying Soviet views on nuclear war fighting and its consequences, which I have sought to derive from studies of Soviet military doctrine and strategy, targeting and weapon employment concepts and especially of the Soviet civil defense program, which deals with Soviet views on the effects of a nuclear war and the character of the post-attack environment.

My interest in the Soviet approach and contribution to the so called Nuclear Winter issue began with my participation at the 1983 International Seminar on Nuclear War held in Erice, Italy, at which V. Aleksandrov of the Computing Center of the USSR Academy of Sciences first presented the findings of the first Soviet model of the climatic consequences of nuclear war. It was further spurred by the conversations I had there with Aleksandrov and the Vice-President of the USSR Academy of Sciences, Ye. Velikhov. This led in 1984 to a quick survey sponsored by DNA on Soviet studies and exploitation of the Nuclear Winter hypothesis covering the years 1983-1984. The primary objective of my study was to examine the question whether, as the Soviets publicly claimed, Soviet scientists had in fact independently verified the findings and predictions of the Crutzen-Birks paper published in 1982 in Ambio and more importantly those of the so called TTAPS study, published in 1983.

My conclusions were that there was no real basis for this Soviet claim. What the Aleksandrov and Stenchikov 1983 computer model had done was to uncritically use the scenarios and assumptions about amounts of fire, soot and dust and their distribution from the Ambio and TTAPS studies. Aleksandrov acknowledged that he had obtained the TTAPS findings in April 1983 during a presentation made of them in Cambridge, Massachuettes, and had, simply used the TTAPS assumptions not for the base-line case but for a 10,000 MT exchange scenario. The initial findings were further distorted by an error of a factor of more than three in interpreting the radiative effects of the TTAPS estimate of optical depth by treating dust as smoke and by assuming that smoke would absorb 100 percent of the incident solar radiation, which was the equivalent of assuming an injection of some 1,000 Tg of smoke instead of the 225 Tg assumed in the TTAPS study.

SOVIET RESEARCH ON GLOBAL EFFECTS (CONTINUED)

A great deal has been written about the shortcomings and errors of the original Aleksandrov/Stenchikov computer simulation model and the assumptions underlying it. The Soviets were slow in acknowledging and correcting the errors in their computations and findings. Subsequently Aleksandrov did modify his model, at least to some extent. He did look at the 100 MT TTAPS case, at moving smoke and scavenging, the transport of smoke to the southern hemisphere, and reduced somewhat the amount of injected smoke in his computations. The model also assumed significant heating at higher elevations, such as the Himalayas and other mountain peaks. Overall, it could be said that the Soviet contribution to the 1983-1984 Nuclear Winter research remained limited to the Aleksandrov/Stenchikov computer simulation model using TTAPS scenarios and assumptions, which represented a seriously flawed effort, It was quickly outdistanced by modeling done in the West. The Aleksandrov/ Stenchikov work was initially only published in English, and to this day continues to be cited by its English title in Soviet Russian language publications. An abridged version of this model was eventually published in 1984 in a Soviet mathematics journal. As to the Aleksandrov/Stenchikov 1984 paper "Update on the Climatic Impacts of Nuclear Exchange," it seems to have been generally ignored in Soviet publications and articles on Nuclear Winter, and appears to have had no significant effect on Aleksandrov's presentation at a meeting of East-European scientists which was held in November 1984.

There is little doubt that during 1983-1984 the Soviets sought to gain maximum propaganda value from their more extreme findings on Nuclear Winter effects, just as they did from other studies of global medical and biological effects on nuclear war using worst-case Western scenarios (WHO). The basic message which Soviet propaganda sought to convey was that nuclear war, and especially Nuclear Winter is not survivable and that so-called limited use of nuclear weapons (a concept attributed to the U.S.) would lead to as serious catastrophic consequences as a full scale nuclear exchange. Without questioning the sincerity of individual Soviet scientists, one could come to the conclusion that from the Soviet viewpoint the Nuclear Winter issue was treated less as a serious scientific issue requiring careful scientific inquiry, although one must recognize the limitations of the computational resources at the Academy's Computing Center, than as a propaganda opportunity in support of the Soviet peace campaign.

It may be worth noting that in 1984 some Soviet academicians writing in domestic Soviet publications, expressed "indignation" at what they claimed to be attempts by some Western scientists to moderate the worst-case predictions of the Nuclear Winter phenonemon. They condemned these attempts "to cast doubts on the conclusions reached" by the "joint efforts" of Soviet and American scientists who were said to have "firmly established the existance of such global threshold phenomena." The articles protested the alledged efforts of some Western scientist to "discredit the results of the work of conscientious researchers (presumably including Aleksandrov/Stenchikov) who are opening people's eyes to the danger threatening them." /For example, see Academician V. Goldansky and Professor S. Kapitsa, "To Prevent a Catastrophe," Izvestiya, 25 July 1984./

SOVIET RESEARCH ON GLOBAL EFFECTS (CONTINUED)

Although on various occasions a number of Soviet scientist members of various Soviet institutes have expressed interest in the Nuclear Winter issue, in practice there was little forthcoming from them during 1983-1984. Indeed, despite some Soviet improvements in their modeling they did not eliminate some of their serious errors until 1985. After a year or so of so-called Soviet collaboration with the International Nuclear Winter Research effort, Dr. Turko noted that, aside from Aleksandrov's computational modeling work, there had been "no substantial physical data and little evidence of objective scientific analysis forthcoming" from the Soviet side. A public request by Dr. Sagan in November 1983 to Soviet scientists for data on the particle size distribution function of debris from Soviet atmospheric nuclear weapon tests before 1963, for information on particle size and absorbtion coefficients from large fires in the Soviet Union, and for Soviet views on the more likely nuclear war scenarios has remained essentially without response. True in 1984 and 1985 there has been talk of the Soviets conducting various fire experiments, but there is no indication that these have been carried out. Indeed in the summer of 1984 the Soviets indicated that the modeling of large fires was beyond the capacity of the computers at the Academy's Computing Center. The Soviets say that they have some data on fires but have difficulties interpreting them. Nevertheless one might note that the Soviet Nuclear Winter studies make no reference to or use of the data on the massive Siberian forest fires in the summer of 1915 which are discussed in Soviet fire literature. No mention is made of other large forest and peat fires, such as those in 1972. In both cases, very large areas, (2.6 million square miles in 1915) were subjected to heavy persistent smoke.

Soviet research into and publications on global effects offer a mix of serious scientific inquiries and what may be more properly characterized as science propaganda. The public aspects of the Soviet work do not reflect the existence of private differences of opinion among Soviet scientists and skepticism about some of the published findings, which, however, become evident in non-public or private discussions between American and Soviet scientists. Of course, no public debate of the sort practiced in the West is permitted in the Soviet Union, especially on issues which Soviet propaganda likes to exploit.

Soviet work on global effects, and especially on Nuclear Winter, suffers, at least as far as its public aspects are concerned, from a number of constraints. One of these is the absence of Soviet war scenarios and the prohibition on public discussion of potential effects of nuclear strikes on the Soviet Union in terms of potential targets which may be attacked, likely urban and forest fires, fallout patterns and so on. True, Soviet literature on weapon effects and civil defense discusses fires and fire propagation, fallout, radioactive contamination, average fuel loading in cities and fuel loading requirements for fire storms and so on, but these are discussed in the abstract and never in terms of specific Soviet cities, targets or regions. When it comes to such specifics, the Soviets fall back on citing Western data on what could happen to the U.S. or Western Europe in the event of an attack. Even when the Soviets illustrate the point that a $2^{o}C$ decline in ambiant temperature will damage crops, they cite the case of such an effect on the Canadian wheat crop. Furthermore, for propandanda reasons the Soviets tend to rely on worst case Western scenarios, no matter how unrealistic. It is difficult to believe, however, that there are no Soviet scenarios and independent assessments of the effects of nuclear strikes in the light of such scenarios. Unfortunately, these are not shown to the West, and indeed, they are likely to be classified.

Another constraint, or so we are led to believe, is the limitation on the capabilities of Soviet computers, which, however, does not explain the tenacity with which the Soviets have perpetuated some of the errors in their computations over a number of years. Still another factor appears to be bureaucratic, i.e., the question of who is going to lead the research effort, which institute will be given a leading role, and how this research fits into the planning of the work of the Soviet science establishment. During 1983-1984 the leading role was played by a small group of people in the Academy's Computing Center, under the leadership of V. Aleksandrov, who, were only interested in the mathematical modeling of atmospheric and biological processes, but had little expertise in atmospheric physics, fire phenomenology, chemistry, etc. and, therefore, were only too willing to use uncritically Western data. The involvement of other institutes with staffs having such qualifications, such as the Academy's Institute for Atmospheric Physics or Dr. Yuri Israel's Laboratory for Maintaining of Natural Environment and climate, to data has been limited. While Velikhov may have been directing the overall effort, the bureaucratic problem appears to have become seriously aggravated by V. Aleksandrov's mysterious disappearance in Madrid in March 1985 during a speaking engagement, given that he was the leader of the main Soviet Nuclear Winter effort and its primary spokesman in the international scientific community. It is noteworthy, that in the most recent Soviet English language publication on Nuclear Winter, The Night After, Aleksandrov's name has disappeared from all references to his 1983 study. In effect, poor Aleksandrov may be becoming a non-person in his own homeland, which may also suggest that international collaboration in Nuclear Winter research may, under some conditions, not be devoid of serious hazards to the health of Soviet scientists. It has been pointed out to me, however, that in a recently published monograph by Stenchikov and Dr. Carl of the GDR Academy of Sciences, issued by the latter, Aleksandrov's name was cited in the references. We may be seeing a case of his resurrection, at least in name, in the GDR if not the USSR.

It should be emphasized that Soviet scientists are not newcomers to research into the effects of nuclear war. They have carried out such work for a long time. Their work, however, has tended to focus on the distribution of radioactive fallout, the problems of long term contamination by radioisotopes, the biological and ecological effects of radiation, and the effects of the introduction into the atmosphere of various chemical aerosols, etc. A reading of Soviet publications also reflects a strong concern, still ongoing, in the problem of depletion of the ozone layer. Soviet scientists have brought up the point about sunlight absorbtion by nitrogen oxides, said to have been observed during Soviet atmospheric nuclear tests during the 1960s, and about the effect of large amounts of greenhouse gases released into the lower atmosphere, which, it is said, could lead to localized "Nuclear Summer" effects. It may well be that the Soviets have more to contribute in the field of atmospheric chemistry and effects of injections of various aerosols then in the modeling of Nuclear Winter.

SOVIET RESEARCH ON GLOBAL EFFECTS
(CONTINUED)

While we continue to see a mix of Soviet science research and propanganda, there is some recent evidence of Soviet attempts to provide more realistic stimulations, and to rely on less extreme scenarios, although these continue to be borrowed from Western sources. For example, in the book, The Night After, published in 1985, we find a slick propaganda piece by Velikhov along with a revised model by Stenchikov which he did jointly with Carl. Among other changes the Stenchikov computations use an initial absorbtion optical depth of 2.2 rather than 6 as in the old model, more scavenging, narrower initial latitudinal spread of aerosols and so on, which also results in a reduction in the calculated temperature changes, and brings them more in accord with the Western studies. In a chapter by Yu Israel, he uses a base line scenario of 5,000 MT and notes a low probability of the injection of significant amounts of aerosol particles from forest fires into the stratosphere. At the same time, however, in a press conference given by Stenchikov's chief, Academician N. Moiseyev in November 1985 he kept citing the findings of the old Soviet models rather than those of Stenchikov. Also in 1985 a pamphlet on Disastrous Effects of Nuclear War - Socio-Economical Aspects was published primarily in English, French, German and Spanish, under the auspices of the Soviet Scientific Research Council on Peace and Disarmament with an editorial board headed by Academician P.N. Fedoseyev. The authors' claim about the socio-economic consequences of nuclear war are clearly predetermined by their claim that "the main target in a nuclear war are people and their civilization, not the military systems of the states".

The Soviet contribution to the study of the biological effects of nuclear war has also been characterized by a mix of science and propaganda. The latter has been particularly noticeable in the case of the work carried out at the Computing Center under the leadership of Yuri Svirezhev and his attempt to have his paper adopted by SCOPE despite its obvious lack of realism and the use of obsolete Nuclear Winter projections and other seriously wrong assumptions and computations all of which were intended to make the worst possible case for the global effects of nuclear war.

It is not clear at present how the Soviet effort to study global effects is organized and whether it has a sense of direction. Although there are indications of interest in these problems among Soviet scientists, the Soviet effort appears to be rather modest in scale, and by no means all the work done has been readily accessible to Western scholars. In the absence of an indepth, comprehensive analysis, which remains to be undertaken, one gains the impression that in terms of its scope, level of effort and richness the Soviet Nuclear Winter research program lags far behind comparable programs and efforts carried out in the West. The Soviet contribution is still largely limited to computer simulations despite the weaknesses of Soviet computer capabilities. Naturally, for scientific and all the more political reasons, Soviet scientists can be expected to continue to participate in the international cooperative effort to study the global effects and consequences of nuclear war. Of course, there can be departures from this practice, such as the last minute failure of Soviet scientists to attend the International Seminar on Nuclear War in Erice in 1985.

SOVIET RESEARCH ON GLOBAL EFFECTS (CONTINUED)

For all the Soviet public promotion, largely in the West, of what could be characterized as a worst case image of the consequences of a nuclear war, there are no clear answers as yet to the questions I mentioned at the beginning concerning the reasons why it is important to assess Soviet research into global effects and to seek to identify actual Soviet perceptions and concerns regarding their implications. My present intentions are not only to update and improve my study for DNA on Soviet research and exploitation of Nuclear Winter, but also to carry out an in-depth inquiry into Soviet research and actual views on all aspects of the post-nuclear attack environment. For this purpose I intend to analyze, with help from physical scientists, not only Soviet research results more widely circulated in the West, but also Soviet research which is only reported in Soviet Russian language sources and which may not necessarily always be specifically identified as dealing with global nuclear war effects although it may be relevant to them. As I have mentioned, there is a substantial body of Soviet fire and nuclear effects literature and relevant scientific papers published by the Academy, the universities or appearing in a variety of Soviet Technical Journals. I also intend to use in my analysis whatever I can learn about what has transpired at meetings and conversations between Soviet and Western scientists. The latter information may be especially valuable for setting Soviet research and views of the Soviet science establishment in better perspective and for gaining a clearer appreciation of true Soviet concerns and priorities.

In my work so far I already owe a great deal to the kind help of a number of scientists who have not only provided me with copies of Soviet research papers they have received from Soviet scientists but also notes on their conversations with Soviet scientists. I hope that with the indulgence of our scientific community my research will also continue in the future to benefit from this invaluable assistance to my further work in this field.

Human Susceptibility to Gamma Radiation

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doses of radiation, at least 0.3 r per week (§ 8.4), for long periods of time without any apparent harmful consequences.

11.27 The foregoing considerations account for the necessity for distinguishing between acute exposure, i. e., occasional large doses, and chronic exposure, i. e., continued exposure to small doses, of radiation. As far as the effects of the atomic bomb are concerned, the situation is simplified by the fact that the initial nuclear radiations are emitted for a short period, taken as about a minute or so, so that exposure to these radiations may be regarded as being of the acute type. On the other hand, the residual radiations, due to fission products, etc., would represent a chronic hazard, either as internal or external radiation.

11.28 Because large acute doses have been accepted by human beings only as a result of accidents of one kind or another, it is not possible to state definitely that a particular amount of radiation will have certain consequences. Nevertheless, from experiments with animals, whose sensitivity to radiation relative to that of human beings has been studied, certain general conclusions have been drawn. These cannot be exact, in any event, since there are marked variations among individuals insofar as sensitivity to radiation is concerned. The results given in Table 11.28 may therefore be regarded as an approxi-

TABLE 11.28

PROBABLE EARLY EFFECTS OF ACUTE RADIATION DOSES OVER WHOLE BODY

Acute dose	Probable effect
0–25 r	No obvious injury.
25–50	Possible blood changes but no serious injury.
50–100	Blood-cell changes, some injury, no disability.
100–200	Injury, possible disability.
200–400	Injury and disability certain, death possible.
400	Fatal to 50 percent.
600 or more	Fatal.

mate indication of the early effects on human beings of various acute doses of radiation, assuming exposure of the whole body.[7] Somewhat larger doses may be accepted, with an equivalent likelihood of injury, if the exposure is protracted over several days or weeks, or if it is limited to a portion of the body. For these extended or split-up exposures, however, it is not possible to give any satisfactory rules for estimating the risk factors.

[7] The possible delayed effects of radiation are being studied in Japan as part of a long-range program of the Atomic Bomb Casualty Commission of the U. S. National Research Council, sponsored by the Atomic Energy Commission. Apart from cases of cataracts (§ 11.71), nothing significant has been observed 4 years after the atomic explosions.

Broyles

11.29 Because of the variations among individuals, it appears that an acute dose exceeding 200 r may prove fatal to a human being, the probability increasing with the dosage. The general variation of the survival rate with dosage for rabbits and rats is represented in Fig. 11.29, and from the results the corresponding curve, shown dotted, for human beings has been inferred. It would appear that an acute dose of 200 r would prove fatal to about 5 percent of those exposed, while an almost equal proportion would be expected to survive a dose of 600 r.

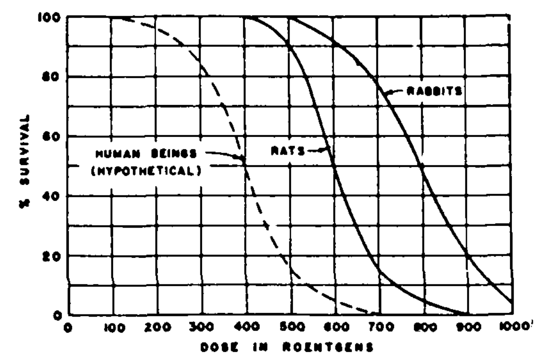


Figure 11.29. Percentage survival as function of acute radiation dosage.

11.30 Most of the victims of the initial nuclear radiations from the atomic bombings of Japan were exposed over a large part of their bodies, since clothes are no protection against gamma rays. From the observations made, much information has been obtained concerning the symptoms and development of radiation sickness of different degrees of severity. For convenience, the description given here will refer to three main degrees of exposure within a short period of time.[8] They are: (*a*) lethal dose, i. e., about 600 r or more, which is fatal in nearly all cases within 2 weeks of exposure; (*b*) median lethal dose, i. e., about 400 r, resulting in death to 50 percent of the patients from 2 to 12 weeks after exposure; and (*c*) moderate dose, i. e., from 100 to 300 r, which is generally not fatal.

11.31 It may be mentioned that in Japan deaths from radiation, in those protected from blast and burns, began about a week after exposure and reached a peak in 3 to 4 weeks; these were probably the

[8] There are, of course, no sharp lines of demarcation between the three postulated types of exposure; the distinction, which is one of degree only (cf. Fig. 11.29), is made here for the sake of convenience in description.

883555°—50——23

Acute LD_{50} 350 - 600 rads

more likely 450 - 600 rads

Body repair can raise the LD_{50} by 4 or more

$$
\begin{aligned}
\mathbf{E} &= \int_o^t \mathbf{f}\,(\mathbf{t}')\,\mathbf{R}\,(\mathbf{t}')\mathbf{dt}' \\
\mathbf{R}(\mathbf{t}') &= \textbf{dose rate} \\
\mathbf{f}(\mathbf{t}') &= \textbf{fraction repaired}
\end{aligned}
$$

bone marrow injection for 50% survival	$= \frac{2\times10^7 \text{ cells}}{\text{kg body wt.}}$
injection fraction reaching bone	$= \mathbf{0.3}$
additional factor for no hospital	$= \mathbf{10}$
number of marrow cells normally	$= \mathbf{10^{10}/kg}$

Fraction of cells required for 50% survival

$$\mathbf{F}_{50} = \mathbf{2}\times 10^{7} \times 0.3 \times 10/10^{10}$$
$$= \mathbf{6}\times 10^{-3}$$

Cell fraction surviving

$$\mathbf{F} = \mathbf{e}^{-D/D_o}$$

a radiation dose D

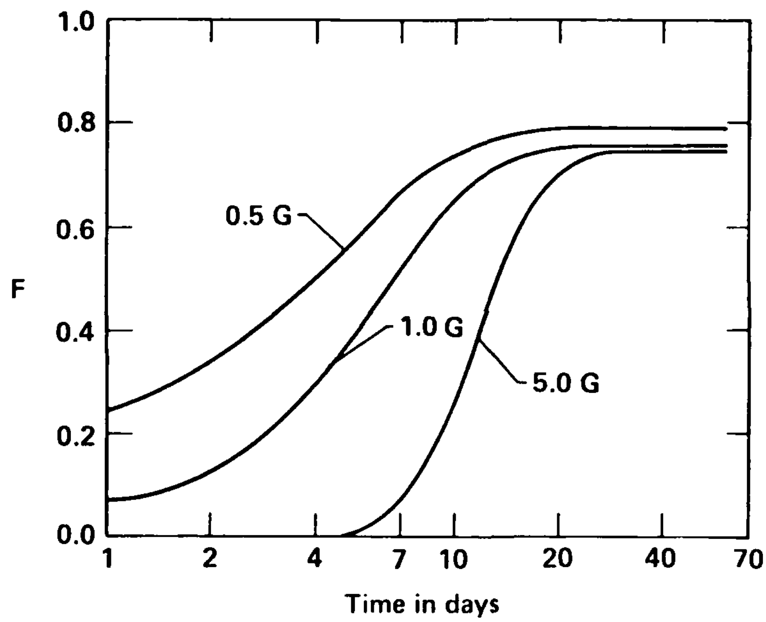
$$\mathbf{D}_o = \mathbf{61.4\ rads}$$

$$F_{50} = \exp(-LD_{50}/61.4) = 6\times10^{-3}$$

$$LD_{50} = -61.4 \ln F_{50} = 316 \text{ rads}$$

Body shielding 0.7

$$\text{External } LD_{50} = 316/0.7 = 451 \text{ rads}$$


1.0
0.8
0.6
0.4
0.2
0.0
F
0.5 G
1.0 G
5.0 G
1
2
4
7
10
20
40
70
Time in days

$$\mathbf{E} = \int_o^t \mathbf{f}(\mathbf{t}') \, \mathbf{R}(\mathbf{t}') \, \mathbf{dt}'$$

$$\mathbf{E} \simeq \mathbf{a} + \mathbf{b}/\mathbf{R}^{1/3}$$

Radiological Dose Assessments From Nuclear War

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Abstract of presentation at the Defense Nuclear Agency (DNA) Global Effects Program Technical Meeting: February 25–27, 1986; NASA Ames Research Center.

Recently we undertook an assessment of the radiological dose following a nuclear war as part of the ICSU-SCOPE-ENUWAR study published as "Environmental Consequences of Nuclear War; Vol. I, Physical and Atmospheric Effects." The following are suggested as follow-on research topics to this subject.

1. Evaluate internal dose contributions in a post-nuclear war environment. For a normal atmosphere, various researchers have provided means to calculate organ dose for many nuclides and food pathways. These calculations will not apply to an environment perturbed by "nuclear winter" effects.
2. Extend the calculations of global fallout to include the stratospheric contribution in a smoke-perturbed atmosphere using a fully interactive GCM.
3. Improvements to the local fallout code KDFOC2 and its documentation.
4. Improve understanding of the radiological dose commitments associated with the potential targeting and damaging of civilian and military nuclear fuel cycle facilities.
5. GLODEP2 code improvements and scenario calculations for global fallout. Code improvements, parameter sensitivities and scenario studies will be conducted.
6. "Reconcile" local fallout code differences. To investigate and communicate on local fallout code differences and establish benchmark type problems related to nuclear winter.

This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

MODELS

GLODEP2: Estimates gamma ray dose from global fallout.
Authors: L. Edwards, T. Harvey, K. Peterson
Reference: UCID-20033 (1984)

GRANTOUR: Calculates the 3-D transport, diffusion, and wet and dry deposition and dose from tropospheric global fallout.
Authors: J. Walton and M. MacCracken
Reference: UCID-19985 (1984)

KDFOC2: Calculates local fallout.
Authors: T. Harvey and F. Serduke
Reference: UCRL-52858 (1979)

MAIN POINTS

* LOCAL FALLOUT CAN COVER LARGE AREAS OF PROTAGONIST COUNTRIES WITH LETHAL LEVELS OF RADIATION (LARGE UNCERTAINTIES).

* GLOBAL FALLOUT IS MORE HAZARDOUS THAN PREVIOUSLY THOUGHT ($\sim$3 → 30 RADS IN N.H. MID LATITUDES)
  N.H. AVERAGE IS ABOUT 15 RADS
  S.H. AVERAGE IS ABOUT 0.5 RADS

* A "NUCLEAR WINTER" ATMOSPHERE REDUCES GLOBAL FALLOUT DOSES BY 15% IN N.H., AND INCREASES THE DOSE MARGINALLY IN S.H. (to $<$ 1RAD).

* "HOTSPOTS" ($\sim 10^6$ KM^2) ARE ABOUT 6 OR 7 TIMES HIGHER THAN THE N.H. AVERAGES.

* SMALLER YIELD DEVICES ⇒ RELATIVELY LARGER DOSES.

* T E GLOBAL FALLOUT POPULATION DOSE IS ABOUT 6×10^{10} PERSON-RADS.

* A "WORST CASE" SCENARIO ATTACK ON NUCLEAR FUEL CYC[illegible] FACILITIES WOULD GREATLY EXACERBATE THE FALLOUT [illegible]

* WE HAVE TREATED MAINLY EXTERNAL GAMMA DOSE. INTERNAL DOSES FROM GAMMAS, BETAS AND ALPHAS ARE [illegible] SIGNIFICANT BUT MORE DIFFICULT TO ESTIMATE. BETA[illegible] CAN HAVE SIGNIFICANT IMPACT ON BIOTA.

IMPORTANT ASSUMPTIONS IN ESTIMATING RADIONUCLIDE EFFECTS

Scenario (total yield, yield mix, number of warheads, etc.)

Fission/fusion fraction

Height of burst

Stabilization height of debris cloud

Meteorological conditions

Scavenging and deposition rates

Time of year

TABLE 8.6. Nuclear war scenario.

Scenario A Knox (1983) 5300 Mt baseline nuclear war		Scenario B TTAPS (Turco et al. 1983) 5000 Mt reference nuclear war	
Total yield/warhead (Mt)	Total fission yield injected (Mt)	Total yield/warhead (Mt)	Total fission yield injected (Mt)
20.0	305	10.00	125
9.0	235	5.00	125
1.0–2.0	355	1.00	213
0.9	675	1.00	319
0.75	15	1.00	25
0.55	220	0.50	187
0.3–0.4	115	0.50	125
0.1–0.2	110	0.30	113
<0.1	1	0.30	75
		0.20	50
		0.10	75
		0.10	12

Nuclear war parameters:
Total number of explosions = 6235

Mt of fission products injected into atmosphere	Scenario A	Scenario B
Polar troposphere	226	369
Lower polar stratosphere	1239	899
Upper polar stratosphere	571	226
High polar atmosphere	0	25
TOTAL	2036	1519

All fission fractions are 0.5.
Scenario A has 47% of its yield in surface explosions
Scenario B has 57% of its yield in surface explosions

TABLE 8.7. Global fallout dose assessments (rads) (unperturbed atmosphere no smoke).

A = 5300 Mt baseline nuclear war (Knox, 1983)
B = 5000 Mt reference nuclear war (Turco et al., 1983)

Latitude band	A_1	B_1	A_2	B_2	A_3	B_3
70–90N	4.5	3.7	2.9	2.5	7.8	8.2
50–70N	27.3	28.8	21.7	22.7	21.3	24.6
30–50N	32.9	41.7	27.4	33.7	22.3	23.9
10–30N	6.9	8.3	5.6	6.6	7.6	7.2
10S–10N	0.8	0.6	0.5	0.3	1.3	1.0
10–30S	0.6	0.4	0.4	0.2	0.6	0.4
30–50S	0.8	0.4	0.6	0.4	0.7	0.4
50–70S	0.5	0.3	0.5	0.3	0.5	0.3
70–90S	0.1	0.0	0.2	0.1	0.2	0.1
Area averaged — N.H.	16.2	19.1	13.1	15.2	12.8	13.7
Area averaged — S.H.	0.6	0.4	0.5	0.3	0.7	0.4
Area averaged — Global	8.4	9.8	6.8	7.8	6.8	7.1
Global population dose ($\times 10^{10}$) man-rads	6.7	8.2	5.5	6.6	5.3	5.5

A_1 — Winter injection using GLODEP2
B_1 — Winter injection using GLODEP2
A_2 — Summer injection using GLODEP2
B_2 — Summer injection using GLODEP2
A_3 — Summer injection using GRANTOUR with stratospheric contributions from GLODEP2
B_3 — Summer injection using GRANTOUR with stratospheric contributions from GLODEP2

Figure 7.5 Global fallout: ac[illegible]ted whole body gamma dose (rads) from 6235 explosions totaling 2031 Mt of fission products (scenario A). An 8 day tropospheric deposition decay constant, characteristic of a winter injection, is assumed.

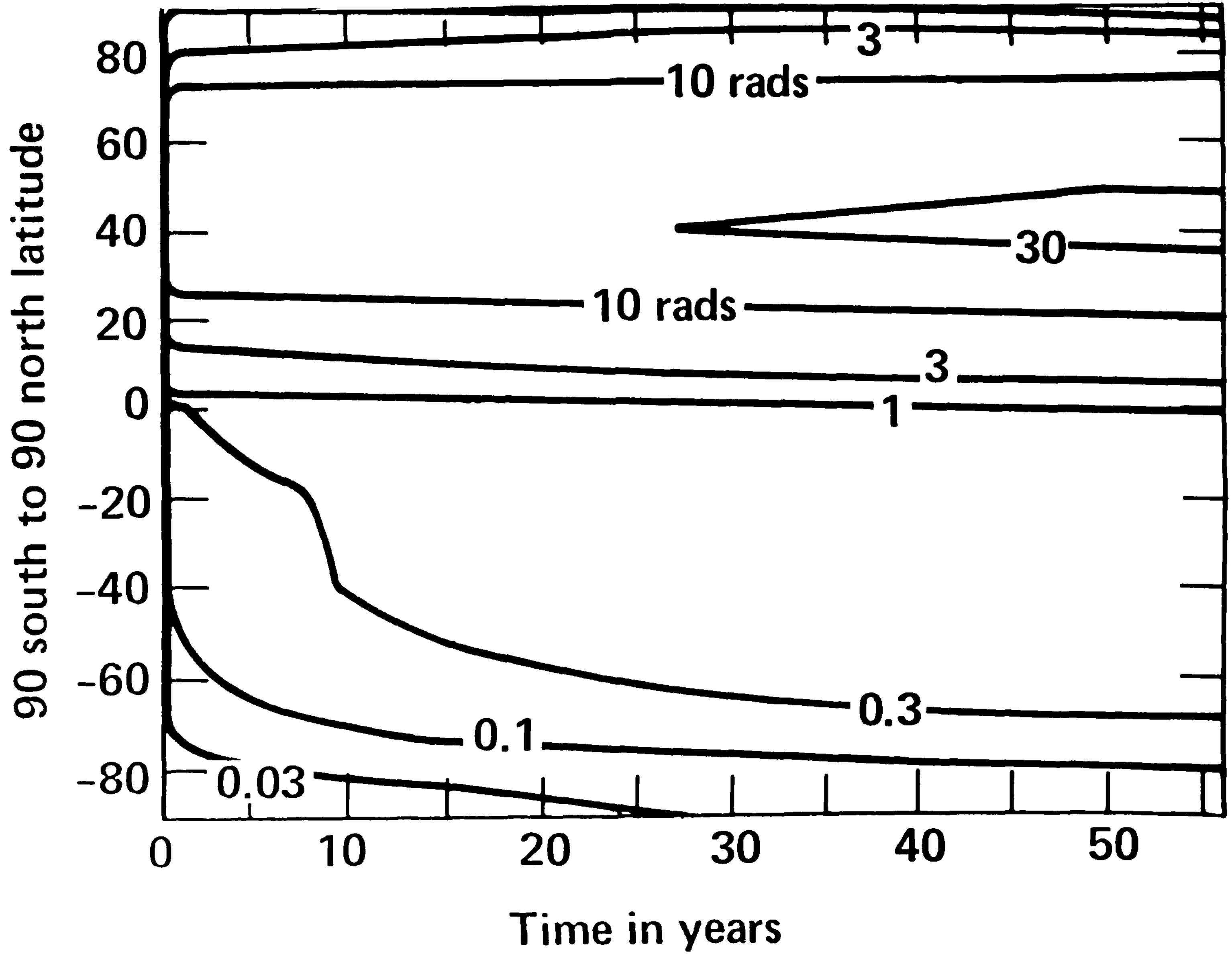


TABLE 8.9. Global fallout dose using three-dimensional GRANTOUR (summer scenario). Comparison of nuclear winter atmosphere (smoke) and unperturbed atmosphere (no smoke). Doses are in rads. Because GRANTOUR only calculates the tropospheric contribution, the doses here include the contributions from the stratosphere as calculated by GLOPEP2.

Latitude band	A_3 (no smoke)	A_4 (smoke)	B_3 (no smoke)	B_4 (smoke)
70-90N	7.8	6.4	8.2	5.8
50-70N	21.3	17.2	24.6	18.0
30 50N	22.3	20.1	23.9	20.4
10-30N	7.6	7.5	7.2	7.2
10N-10S	1.3	1.6	1.0	1.4
10-30S	0.6	0.8	0.4	0.6
30-50S	0.7	0.8	0.4	0.5
50-70S	0.5	0.5	0.3	0.3
70-90S	0.2	0.2	0.1	0.1
Area averaged—N.H.	12.8	11.5	13.7	11.5
Area averaged—S.H.	0.7	0.8	0.4	0.6
Area averaged—Global	6.8	6.1	7.1	6.1
Population average—Global	11.5	10.7	12.0	10.7
Global population dose ($\times 10^{10}$) person-rads	5.3	4.9	5.5	4.9

A_3 = 5300 Mt (Knox, 1983), unperturbed atmosphere (no smoke)
A_4 = 5300 Mt (Knox, 1983), perturbed atmosphere (smoke)
B_3 = 5000 Mt (Turco et al., 1983), unperturbed atmosphere (no smoke)
B_4 = 5000 Mt (Turco et al., 1983), perturbed atmosphere (smoke)

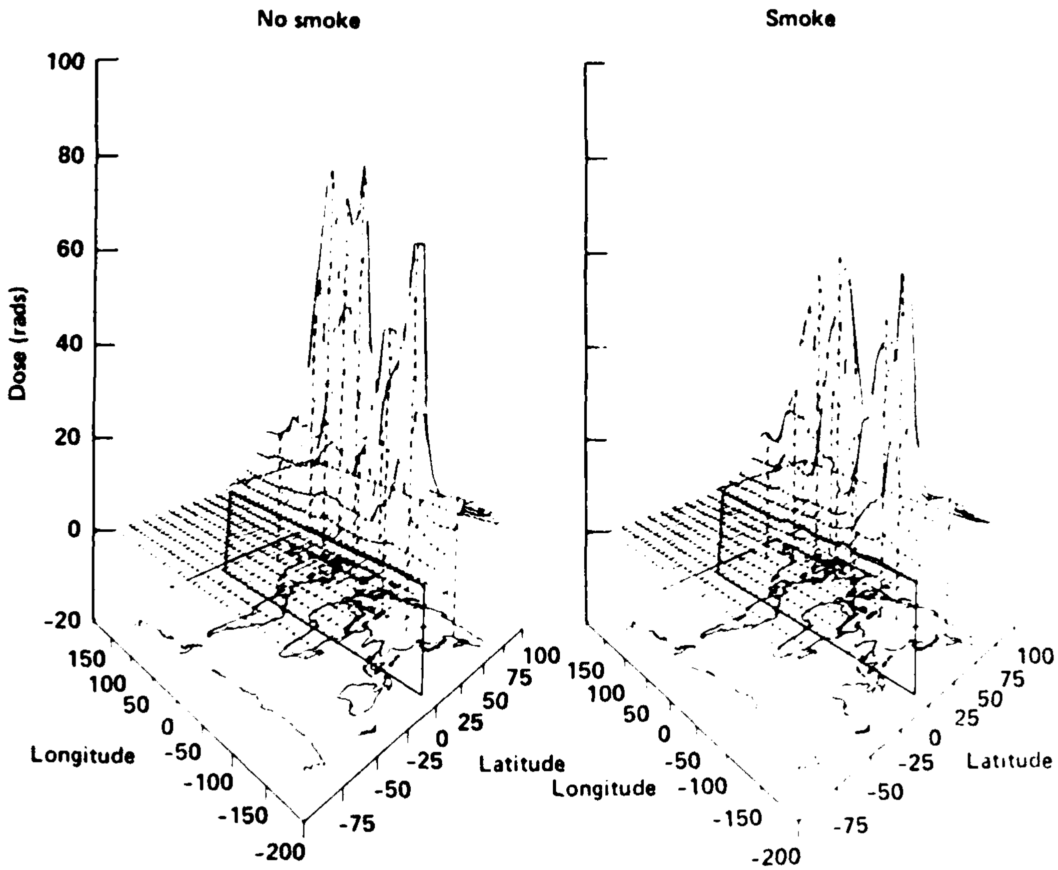


Figure 7.6 Comparison of radionuclide global dose distribution for cases with unperturbed and smoke-perturbed climates (tropospheric contributions only).

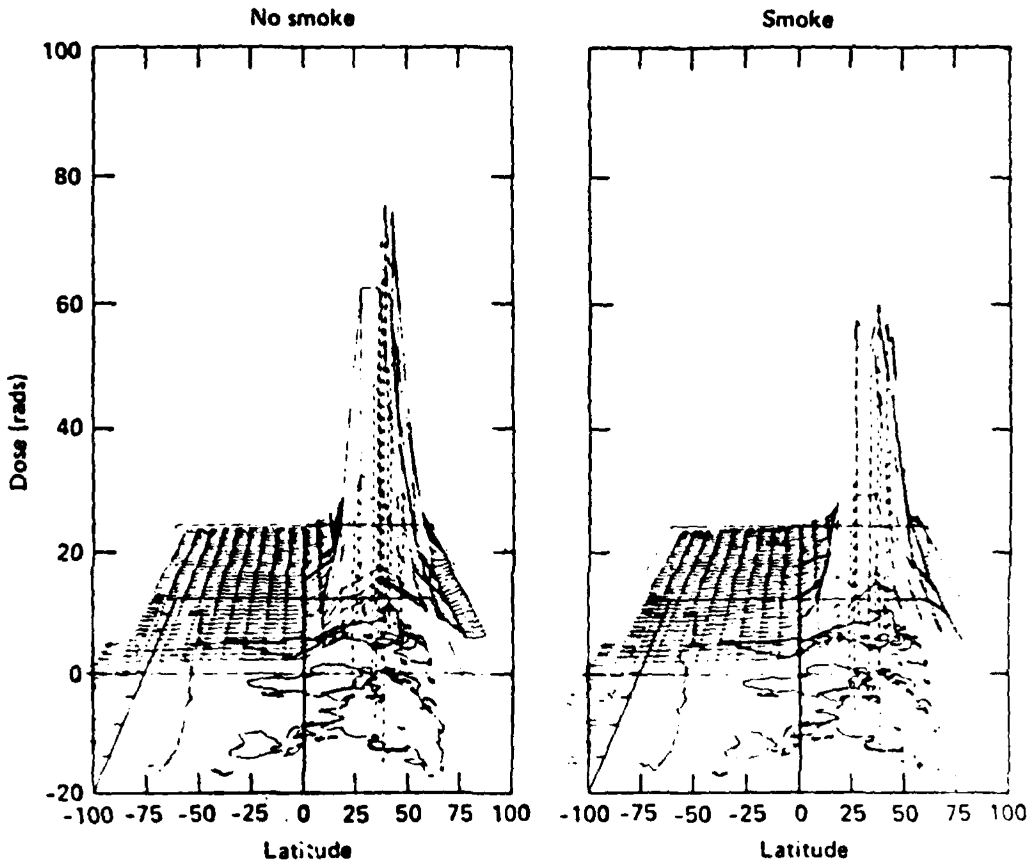


Figure Figure 7.7 Same as Figure 7.6, but a different viewing angle.

Table 7.1 Surface-burst warheads in a phased nuclear exchange. All weapons are assumed to be 50% fission yield.

Weapon yield (Mt)	Number of warheads: Initial counter-force phase	Extended counter-force phase	Industrial counter-value phase	Final phase	Full baseline exchange
0.05	0	300	0	250	550
0.1	975	150	50	8	1183
0.2	0	250	50	121	421
0.3	500	250	0	125	875
0.5	1000	200	0	25	1225
1.0	250	495	160	125	1030
5.0	0	50	15	8	73
Total surface-burst yield	~1000	~1000	~250	~250	~2500

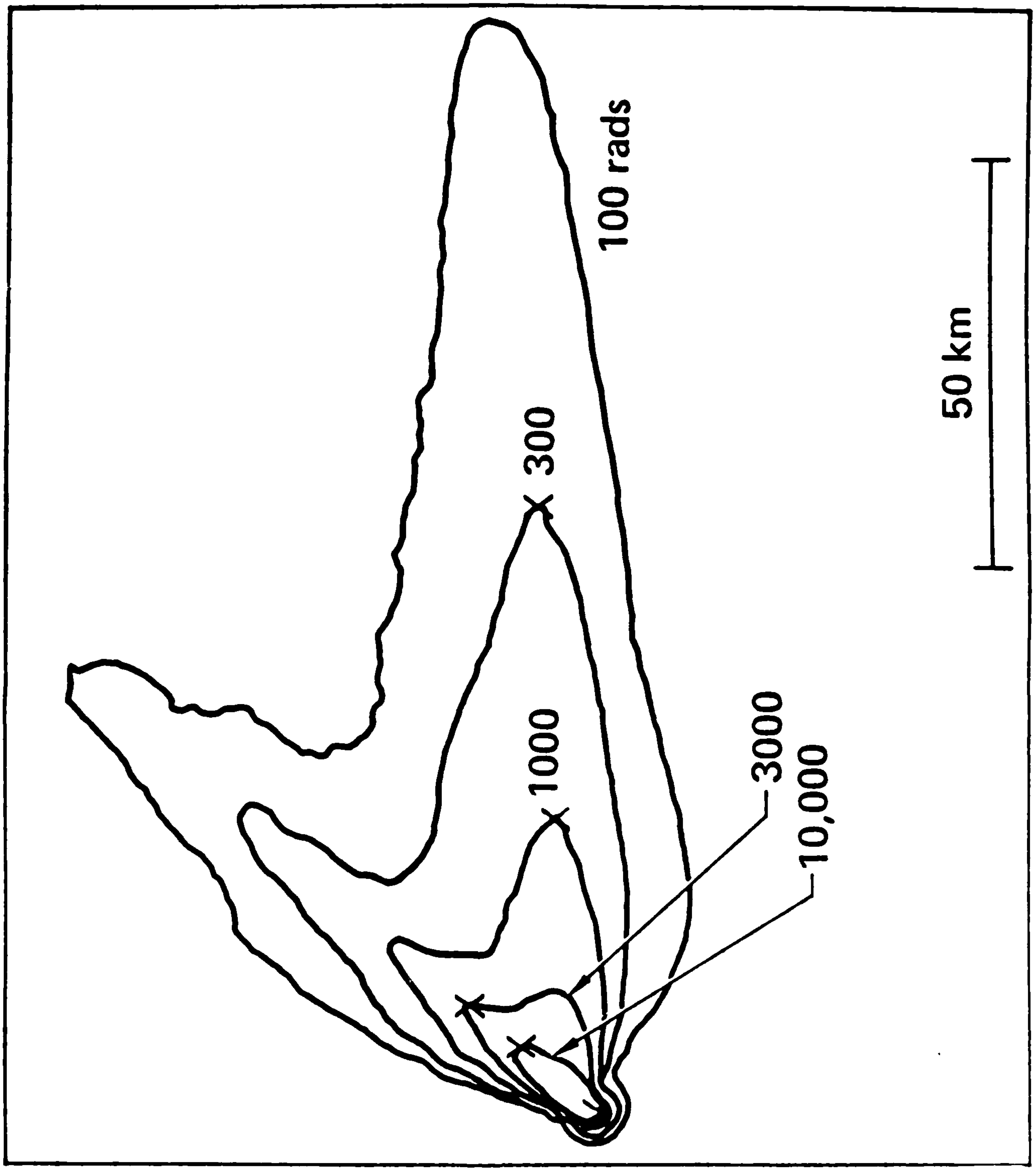
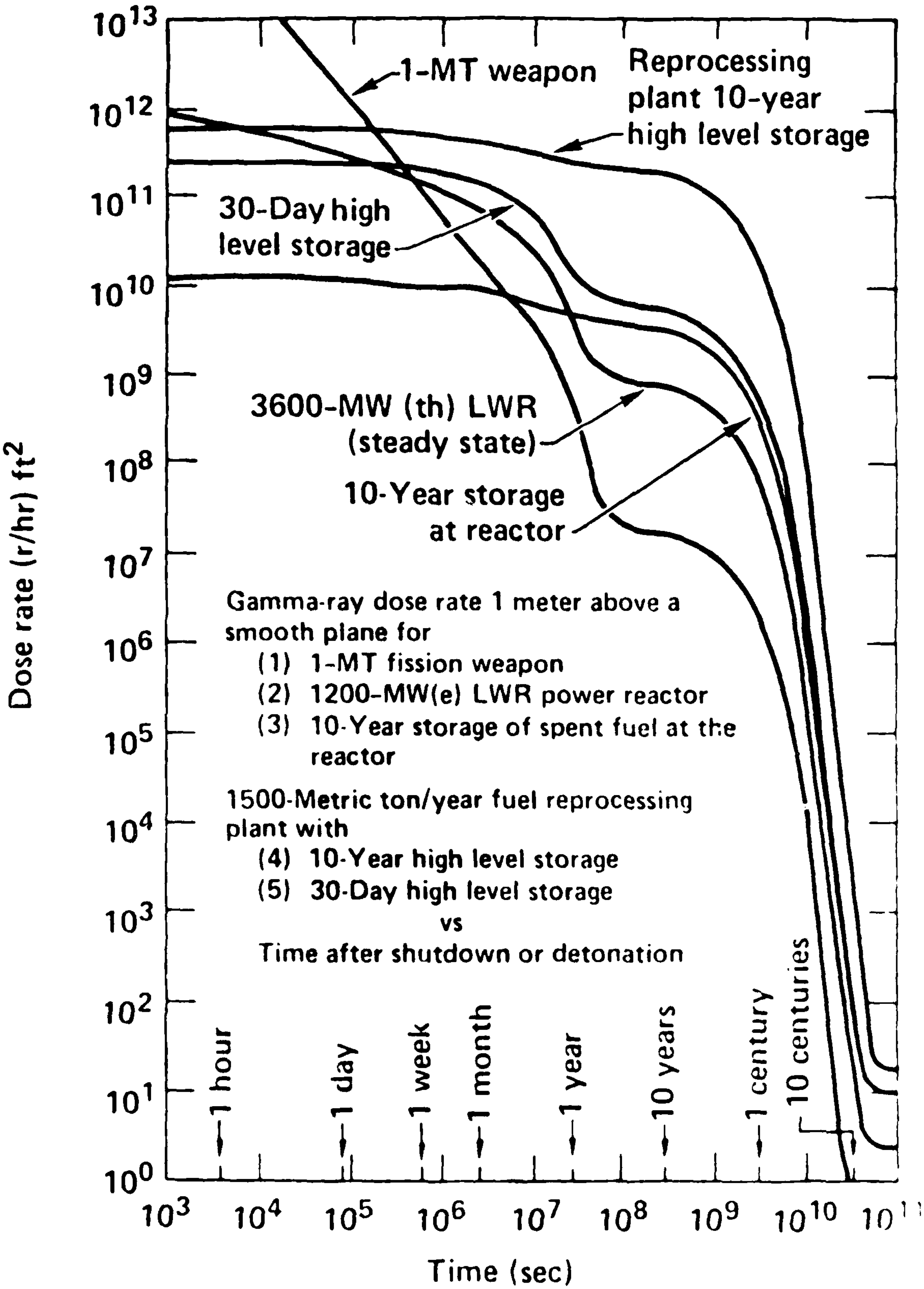


Figure 7.1 48-hour dose predictions for a 1-Mt all-fission weapon detonated at the surface. A mid-continental Northern Hemisphere summer wind profile was used. The double-lobed pattern is due to a strong directional wind shear that is typical during this season. For a 1-Mt weapon, the lofting of radioactivity is so high that topographic features are not expected to play a large role in pattern development; thus, a flat surface has been used. The protection factor is 1. The local terrain is assumed to be a rolling grassy plain.

Table 7.2 Percent of land mass covered by a minimum 450 rad, 48-hour dose.

	Initial counter-force phase	Extended counter-force phase	Industrial counter-value phase	Final phase	Full baseline exchange
Europe	0	2.9	0.6	0.8	4.3
Eastern U.S.S.R.	0.5	0.5	0.1	0.2	1.3
Western U.S.S.R.	1.6	2.3	0.7	1.7	6.3
Eastern U.S.	0	4.7	1.0	1.4	7.1
Western U.S.	4.4	2.3	0.7	6.6	8.0

Figure 9.8. Gamma-ray dose rate area integral versus time after shutdown or detonation (Chester and Chester, 1976).



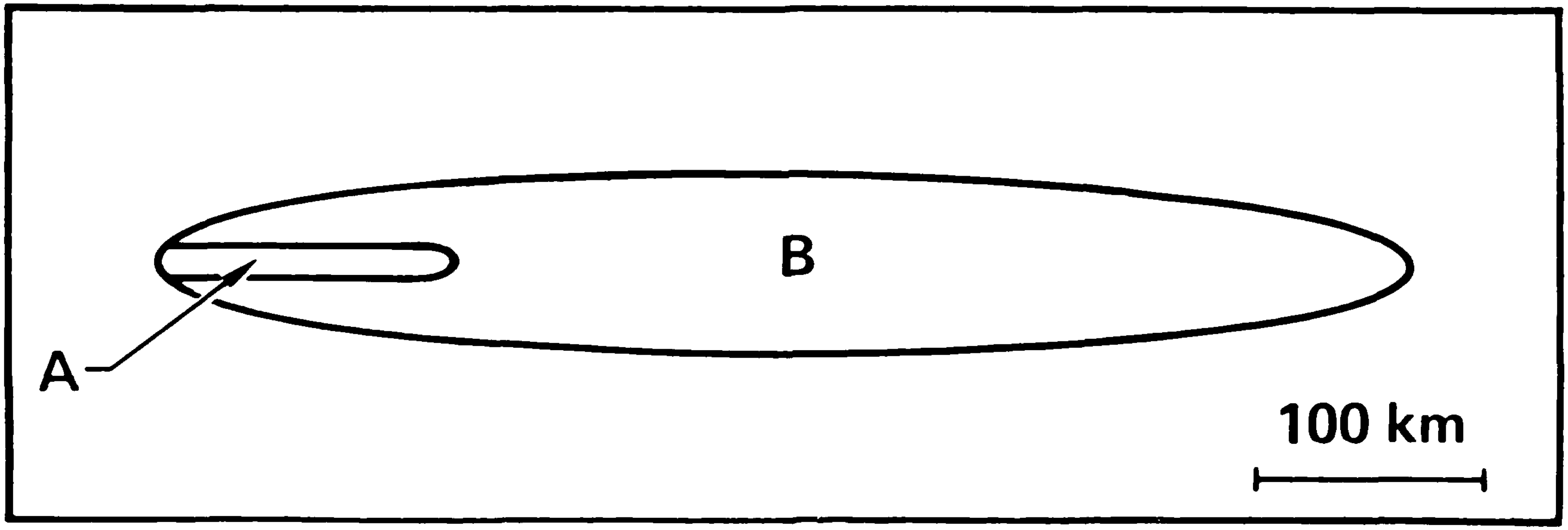
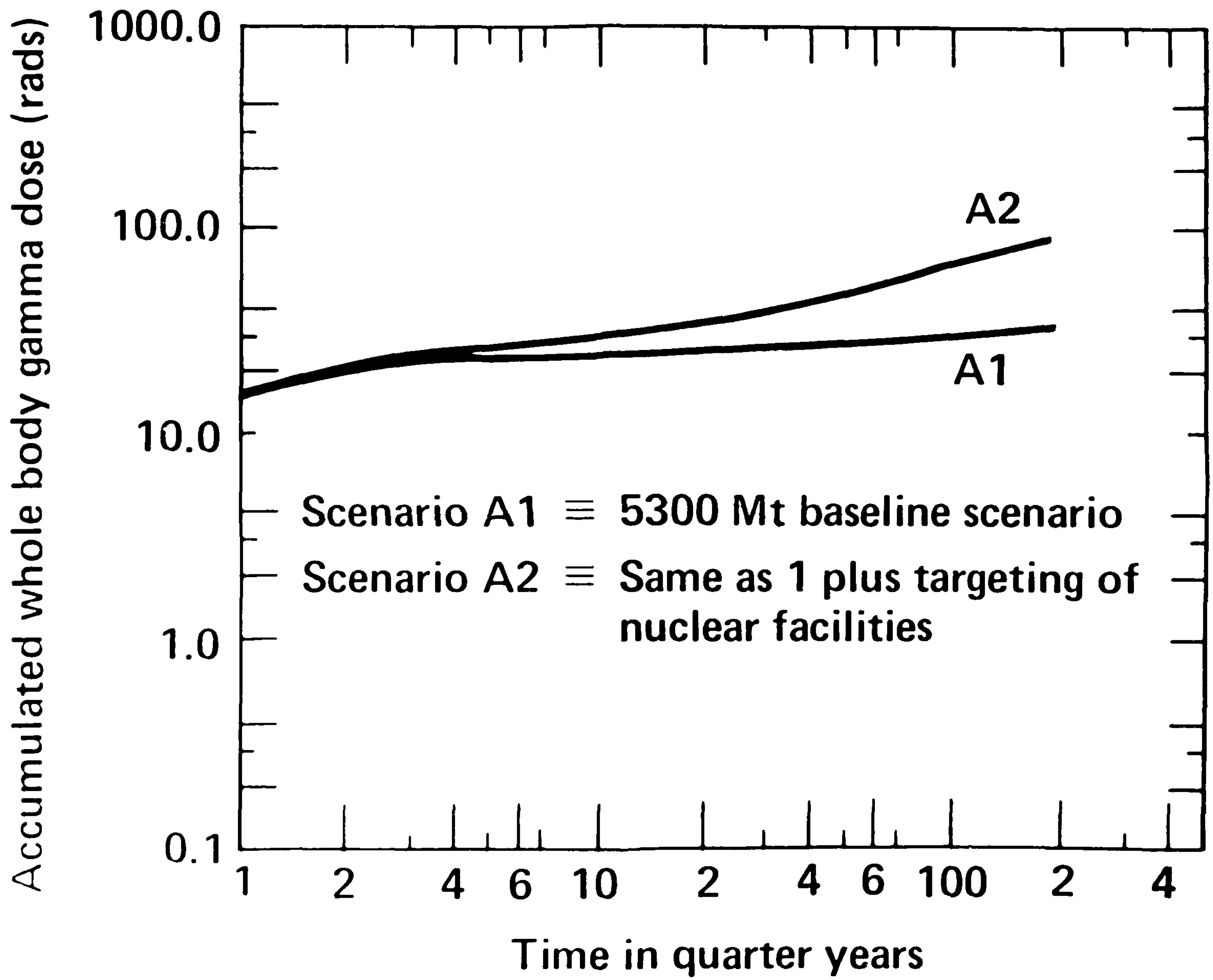


Figure 9.9. Contours of 100 rad (1 Gy) fallout dose in one year, starting one month after the detonation of (A) a 1 Mt bomb, and (B) a 1 Mt bomb on a 1 GW(e) nuclear reactor (Rotblat, 1981).

TABLE 8.11. Uniform 50-year gamma-ray dose in rads as a function of the 9 latitude bands for the weapons and a 100 Gw(e) of nuclear power industry. These values do not take into account any weathering, sheltering or rainfall factors.

	Latitude bands								
Source	90-70N	70-50N	50-30N	30-10N	10N-10S	10-30S	30-50S	50-70S	70-90S
Weapons	4.5	27.3	32.9	6.9	0.8	0.6	0.8	0.5	0.09
LWR	1.8	6.3	9.1	3.0	0.6	0.3	0.3	0.1	0.01
SFS	0.7	23.8	32.7	11.3	2.3	1.0	1.0	0.4	0.03
FRP	1.1	14.6	20.1	7.0	1.4	0.6	0.6	0.2	0.02
TOTAL	17.1	72.0	94.8	28.2	5.1	2.5	2.7	1.2	0.15

Figure 7A.3 Accumulated dose at 30°-50°N vs time for scenario A, with (A2) and without (A1) an attack on U.S. nuclear facilities.



- Forage-cow-milk,
- Pasture- meat (including steer, lamb, and hog meat),
- Leafy vegetable,
- Grains and other non-leafy crops,
- Fresh and salt water fish, and other edible aquatic animals.

- Surface air concentration of the radionuclide,
- Deposition of Cs-137 on the grass or dry feed,
- Fraction of the nuclide that remains on the forage,
- Residence time of the nuclide on the forage,
- Intake rates of both wet (grass) and dry (hay) feed consumed by the cow,
- Concentration in milk,
- Dose per unit activity ingested,
- Infant's milk consumption rate.

- (a) little or no effect,
- (b) slight to moderate effect,
- (c) moderate to large effect,
- (d) large effect.

POSSIBLE FUTURE TRENDS

(1.) Changing Nature of Stockpile and Scenarios

- (a) increased accuracy
- (b) decreased field per device
- (c) decreased total yield
- (d) earth penetrating warheads
- (e) changing targets

(2.) S.D.I.

- (a) targeting of warheads in flight and dispersal of fissile fuel
- (b) targeting of nuclear power plants dedicated to ground based laser stations

The Siberian Megafire of 1915: A National Smoke Injection in the Same Range as "Nuclear" Winter Models

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S'159(1) - REVISED DRAFT SUBMITTED TO NATURE (2/23/86)

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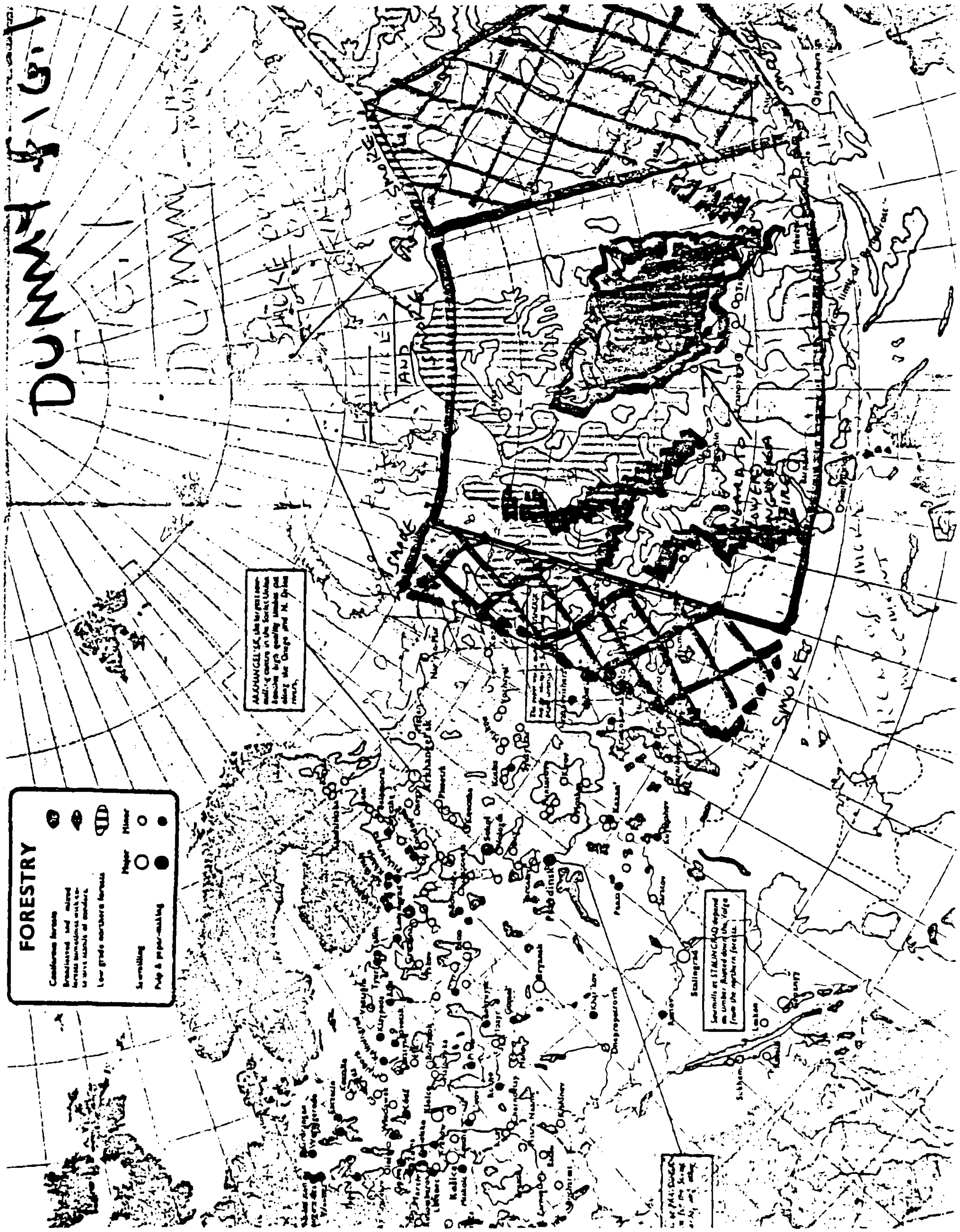
THE SIBERIAN MEGAFIRE OF 1915: A NATURAL SMOKE INJECTION IN THE SAME RANGE AS "NUCLEAR WINTER" MODELS

The reduction in sunlight and temperature over large areas presumed to result from the 20 to 650 teragrams[1] of smoke that could be produced by a major nuclear exchange has been extensively modeled.

Natural analogs of real use in calibrating the models have not been easy to find.[2,3]

However, a uniquely relevant event in the recent past has emerged from obscurity. The vegetation of central Siberia is rich and complex. In the western portion, coniferous forest is interspersed with steppe, birch groves, and peat bogs containing a long-term accumulation of biomass. In the east, larch is the dominant forest species, and permafrost is more extensive. In 1915, a prolonged drought, the worst in two generations, turned the Siberian landscape into tinder. In July and August, often violent wildfires raged from the Ob to the Lena (Fig. 1). In all, seven hundred thousand square miles (roughly 1.8 million square kilometers) burned. The complete devastation of tracts of forest as large as Germany were reported--the


DUMMY FIG 1
FORESTRY
SMOKE

approximately 132,000 square mile belt between the Angara and lower Tunguska Rivers, and 55,000 square miles of accessible economic timber, the most valuable of which was coniferous, were lost. A pall of smoke overspread an area of 2.6 million square miles extending widely beyond the limits of the fires, reaching 8° west and 21° east of the 69° to 112° east longitude belt in which burning occurred--in a generally northeasterly drift. In the densest smoke, day turned to night and the cows came home. Over an area of 702,000 square miles, visibility dropped to between 14 and 70 feet.

Data collected from 350 properly completed questionnaires out of 500 dispatched throughout Siberia by A. Vosnesensky of the Irkutsk magnetic-meteorological observatory were reduced in 1916-17 by him, J. Belyaeff, and V. B. Shostakovitch, and a summary was finally published in English, after a delay due to war and revolution, in April 1925 in the Journal of Forestry.[4]

While these smoke emissions were observed in the lower atmosphere their optical depth, scale, spread, and duration--an average of 51 days--render their behavior and effect on climate, regional and global, as interesting as the hypothetical high-altitude smoke injections employed by the several generations of existing "Nuclear Winter" models.

Using Small and Bush's methodology,[5] the lower bound of

TABLE 1

COMPARISON OF VARIOUS WILDFIRE METHODOLOGIES APPLIED TO SIBERIA 1915

Study	Yield (Mt)	Area (10^3 km^2)	Loading (g/cm^2)	Emission (g/g)	Smoke (10^{12} g)	Siberia (1.8M km^2)
Crutzen and Birks	3800	1000	0.3 to 0.55	0.067 to 0.073	200 to 400	360 to 720
Turco et al.	4000	500	0.5	0.032	80	288
Crutzen et al.	3800	250 to 1000	0.4	0.06	60 to 240	108 to 432
NAS	5000	250	0.4	0.03	30	216
Bush and Small	4100	30 to 190	0.01 to 0.20	~0.03	0.3 to 3.0	18 to 180
(Shostakovitch)	(0)	(1800)	(0.1? to 0.5*)	(.03 to .073)		18 to 720 + humus + peat

* Economic timber losses defined in terms of "3,200 cubic feet" per acre: for wood density ~50 lbs/ft^3, this yields approximately 2 g/cm^2 wood.

the range yields about 40 teragrams of smoke from the forest and taiga fires reported by the Shostakovitch--if the reported combustion of peat, which covers hundreds of thousands of square kilometers of the region, and humus, which is reported to have burned down to its sandy substrate in some areas, is completely excluded from the calculations.

However, using the methodology employed by Crützen and Birks[6] or Turco, Toon, Ackerman, Pollack, and Sagan,[7] the same calculation yields approximately 180 to 720 teragrams of smoke. Including peat and humus could add an additional 1,000 teragrams, for burning up to a depth of two meters, corresponding to a fuel loading of 100 g/cm^2 or more was reported in many places. The 50-teragram "threshold" for global effects may have been exceeded in less than a week at the height of the fires if the high wildfire biomass loadings (.5 to 2.2 G/cm^2) they cite are correct.

"Nuclear Winter" effects are calculated to be most severe in continental interiors in mid-summer,[8] the season when solar-heating-induced buoyancy[9] is most likely to transport smoke generated in the boundary layer into the high atmosphere and beyond the effects of low-altitude removal processes. In 1915, the dilution of optical depth dependent climatic effects was limited by the prolonged confinement of the smoke within Siberia--an area more than an order of magnitude smaller than the 30° to 60°N. Lat. circumglobal belt considered in the model of Turco et al. Each 100 TG of smoke over Siberia corresponds to more than 1,000 TG in their 1-D model. This concentration compensates for the more gradual rate of injection. Given these "worst-case" aspects of the real situation in Siberia, one might expect to have seen climatic and ecological changes on a regional to global scale:[10] effects that could be significant if emissions from these often intense fires were on the level predicted by Small and Bush's methodology, and catastrophic if the model parameterizations of Turco et al., the NAS, or SCOPE are in good correspondence with the vicissitudes of natural history. For, regardless of the altitude at which the modelers elect to inject the smoke they model, it too must have its source on the ground and its origin in the boundary layer.

It is significant that data from Siberian meteorological stations record the coexistence of widespread smoke and sporadic darkness with a hot, dry summer; insolation was reduced by an average of 15% in July and 35% in August. These observations are consistent with the early and unpublished results of 3-D modeling by MacCracken et al., in which standard aerosol injection parameters--altitudes below 1.5 km above surface were applied to "Nuclear Winter" aerosols (the model predicted surface warming--personal communication, M. MacCracken). While this was sufficient to retard the ripening of cereal crops by 10 to 15 days, despite the expectation of an early harvest on account of the elevated temperatures and low rainfall, it scarcely coincides with the collapse of the agricultural ecosystem postulated by Harwell's model[11] of the response of biota to comparable transients in the optical depth of the atmosphere.

Much needs to be done to better quantify the conflagration of 1915. Should Vosnesensky's data base, which was stored at Irkutsk circa 1925, prove inaccessible, a wealth of dendrochronological evidence still survives in the trunks of mature trees in Siberia and could be used to augment the written record of the events in question. The eyewitnesses who remain are nonagenarians whose oral history must be gathered soon or not at all.

Until such data are forthcoming, one of the most edifying experiments available to the climate modeling community might consist in loading the 3-D interactive models[12] with boundary layer smoke of optical depth corresponding to the 1915 reported observations over the appropriate areas of Siberia. One could then allow the computers to run on historical emissions and meteorology[13] rather than purely parametric injections. For the mathematically perfect homogeneity of the smoke in the 3-D global climate model grids is very different from the fractal complexity of clouds in the real world.[14] Will the models depict the collapse of the Hadley Circulation[15] and a frigid end for the tropical rainforests and ricefields of the Third World? Or will 1915, as modeled, resemble the year itself? A slightly warmer than average year in which the echo of the Guns of August drowned out the cries of fire in uncrowded Siberia and the world's attention turned to the terrible realities of the Great War.

The author wishes to thank E. Bauer, G. Carrier, M. Harwell, A. Hecht, and R. P. Turco for their stimulating discussions, M. Kuchement of the Harvard Russian Research Center for his aid in clarifying the geographic extent of the fires, and C. Sagan for first proposing the utility of fire data from the Soviet Union in "Nuclear Winter" research.[16]

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SURFACE TEMPERATURE EFFECTS OF FOREST FIRE SMOKE PLUMES

A proposal

by

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Although it is impossible to study an actual nuclear winter, nature provides us with analogs, occurrences in the actual climate system that can teach us about some of the postulated interactions. Almost every year recently, large forest fires have burned in North America, Asia or the tropics that have produced extensive smoke plumes. Some of these have been measured to have optical depths in the visible larger than 3, as thick as postulated nuclear winter smoke clouds. Although nuclear winter smoke plumes would be a mixture of forest fire smoke and smoke from burning cities (in some scenarios) and hence have different optical properties, we can learn much that is relevant to nuclear winter by the surface air temperature responses to forest fire smoke plumes. The Great Smoke Pall of 1950, resulting from Canadian forest fires, was reported to have lowered daytime surface air temperatures in Washington, D.C., by 6 degrees C after atmospheric residence of one week. Detailed studies of contemporary plumes with adequate data sets will allow us to attempt to verify such effects.

It is proposed here to analyze surface air temperature response to the presence of smoke plumes in the atmosphere. Cases will include forest fire plumes with sources in Western Canada, Montana, Siberia, New Guinea and Borneo that have been identified on satellite imagery during the past 5 years. Surface temperatures under the plume will be compared to those outside the plume by various techniques, including the succesful method of using MOS errors that detected surface temperature effects of the Mount St. Helens dust cloud. Results will be compared to calculations from radiation models.

CLOUD PATCHINESS, TEMPERATURE FLUCTUATIONS, AND THE SEVERITY OF NUCLEAR WINTER

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Abstract

A key limitation of standard numerical models of nuclear winter is the indirect parametrisation of the all important (soot) cloud-radiation interaction, and the associated assumption of homogeneous clouds at sub-grid scales. However, basic ideas in turbulence suggest that soot will be concentrated by cascade type processes into highly inhomogeneous "patchy" regions characterised by strong fluctuations of the form $Pr(\Delta C > \Delta c) \approx \Delta c^{-\alpha}$ for the probability distribution of a soot concentration fluctuation(ΔC) exceeding a fixed threshold Δc. Using various tracers, we empirically estimate the exponent $\alpha_{\Delta C} \approx 3$, whereas for temperatures in normal climate $\alpha_{\Delta T} \approx 5$. Radiation balance arguments suggest that in nuclear winter fluctuations in soot are directly related to surface temperature fluctuations and that nuclear winter may lower $\alpha_{\Delta T}$ from 5 to ≈ 3 yielding much more intermittent temperatures. We argue that for biological systems, the intermittency of the temperature may be as important as the mean, since extreme low temperatures- even if only briefly attained- can do

great damage. We conclude that the patchiness of nuclear winters could make them more severe than previously believed.

1. Introduction:

Due to their limited range of scales, General Circulation Models are not able to handle directly the central physical processes in Nuclear Winter (Crutzen and Birks, 1982, Turco et al. 1983, Alexandrov and Stenchikov, 1984, Covey et al., 1984). In particular, the all-important soot clouds are highly parametrised, and consequently the soot-radiation-temperature interactions are modelled very indirectly. This is very unfortunate, since the biological consequences of a Nuclear Winter are expected to be highly dependent on the intensity, duration, and frequency of occurence of extreme low temperature episodes- not only on the average temperature drop (Harwell and Hutchison 1986). The fundamental significance of such extreme variability have been widely discussed by biologists, under the rubric "variance effects". Below, we directly address this question by relating temperature variability to the patchiness of the soot clouds.

2. How patchiness is produced

The patchiness of clouds can be understood in the context of turbulent cascades. In (scaling) cascade processes, a given quantity (the flux of energy for the dynamics, here the soot) is concentrated step by step down to the smallest scale, by a similar process at each scale. The overall effect of such processes is to concentrate quantities in very sparse regions of the space.

Fig 1 give such an example: a cell - of size ℓ_n - is split, due to non-linear interactions with cells of roughly the same size, in the sub-cells - of size $\ell_{n+1} = \lambda \ell_n$, $\lambda < 1$ being the (constant) scale ratio of the discretised cascade- and its content is randomly distributed among the different sub-cells, in such a way as to conserve (on average) the cascade quantities at each scale. In the homogeneous case (Fig1 a), the quantity is evenly distributed among the different sub-cells and no variations in concentration occurs. However, with a simple modification (Fig 1 b) "dead/alive" sub-cells (no soot/ soot) strong patchiness is produced, and the number of the "alive" sub-cells of size ℓ varies as:

$$N(\ell) \sim \ell^{-D_s},\ D_s < d$$

d being the dimension of the space on which the cascade occurs (e.g. 3, or 4 in space-time space), and D_s is the fractal/Hausdorff dimension of the support of "activity", i.e. where soot is present and even so dense that its density is singular in respect to the usual volume (Lebesgue) measure

As soon as we abandon the alternative "dead/alive" (corresponding to the [illegible] model, Frisch et al., 1978) to the more realistic alternative weak [illegible] (the "α-model", Schertzer and Lovejoy, 1983, 1985a by a whole [illegible] (decreasing) dimensions of the (sparser and sparser [illegible] singular behaviour of the density of the soot

3. Extreme fluctuations as [illegible]

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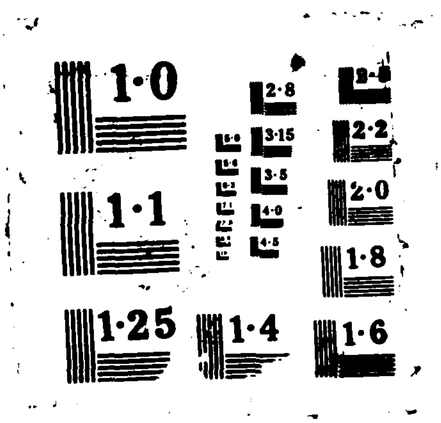
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statistical moments of the soot occurs. The physical reason is that the the density of the soot is so singular that its integration over low-dimensionnal sets is insufficient to smooth out this singular behaviour, of the high order statistical moments. This type of divergence is associated with algebraic fall-off of probability distributions, we may therefore assume that the the probability distribution of the soot concentration (or of its fluctuations) will have "fat tails", e.g.:

$$Pr(\Delta C(\Delta x) > \Delta c) \sim \Delta c^{-\alpha};\ \Delta c \gg 1.$$

where $\Delta C(\Delta x)$ are fluctuations of the concentration C of the soot on a distance Δx, and Δc's are (high) thresholds, α is the intermittency exponent (independant of the spatial or temporal scale). One may note that many meteorological fields have been investigated in this manner: the rain-field (Lovejoy, 1981, Lovejoy and Schertzer1985), dynamics and potential temperature (Schertzer and Lovejoy, 1983, 1985a) and surface temperature (Ladoy et al., 1985, Lovejoy and Schertzer, 1986, Lovejoy et al., 1986). Furthermore, even in strongly anisotropic frameworks, a wide variety of continuous cascade processes are possible, (Schertzer and Lovejoy, 1985b, 1986.

4. A preliminary data analysis:

As appropriate soot dispersion data were not available, analysis of aerosol tracers were used to characterise tracer cloud patchiness. Below, data from SF_6 and CBr_2F_2 tracer experiments (Wilson et al. 1976) were analysed (Visvanathan, 1985, Schertzer et al., 1986). Measuring stations were placed along circles of radii 100m, 200m, 400m, centered on a point source (see Fig.2). The scaling and intermittent behaviour of the concentration of these tracers could therefore be studied over a range of several hundred meters. Though the amount of data was limited, the intermittency exponent of the fluctuations of the concentration was estimated as:

$$\alpha_{\Delta c} \sim 3$$

In support of the scaling hypothesis this asymptotic behaviour of the probability distributions was apparently the same for the different distances studied (fig. 3). The assumption of scaling behaviour over a much wider range of time and space scales is justified by the observations of Doury, 1980 that the r.m.s. width of clouds using a wide variety of tracers (including nuclear clouds), obey algebraic laws. This means that it is not unreasonable to expect $\alpha_{\Delta c}$ to be constant over a wide range of scales. However, large scale fire experiments will be necessary to fully confirm this idea.

6. A rough estimation of surface temperature intermittency:

In the radiative transfer equation, if we consider the emissivity fluctuations to be of second order, with respect to fluctuations of concentration, we obtain a simple relation between the fluctuations of surface temperatures (ΔT) and soot concentration (ΔC):

$$\Delta T/T \sim -\Delta C/4.$$

This crude approximation is consistent with different radiative transfer models (e.g. MacCracken 1983, Penner and Haselman 1983), and implies that the intermittency exponent of the surface temperature ($\alpha_{\Delta T}$) is the same as that of the concentration ($\alpha_{\Delta c}$). In normal conditions (Ladoy et al., 1985, Lovejoy and Schertzer, 1986, Lovejoy et al., 1986) we find empirically:

$$(\alpha_{\Delta T})_{normal} \sim 5$$

we therefore expect far more intermittency in Nuclear Winter conditions, since the present study suggests:

$$(\alpha_{\Delta T})_{\text{Nuclear Winter}} \sim 3$$

This represents a much more frequent occurence of extreme temperatures.

In the near future more sophisticated studies will undoubtly be performed by coupling radiative transfer schemes with cascade models of clouds (see for example Gabriel et al., 1986).

7. Provisional conclusions: "variability effects vs. average effects"

We have briefly indicated how turbulent cascade models provide a framework in which the extreme fluctuations of a Nuclear Winter could be studied both theoretically and experimentally. In particular, they allow us to directly relate the intermittent behaviour of the surface temperatures to the patchiness of soot clouds.

Using SF6 and CBr2F2 as tracers, a preliminary data analysis enabled us to estimate the value of the intermittency exponent of the fluctuations of the concentrations of the tracers. Using a crude approximation of the radiative transfer equation, we argued that under nuclear winter conditions, where temperature fluctuations are likely to be controlled by fluctuations in the radiation field (and this in turn by clould patchiness), that this exponent should be roughly the same as that of the surface temperatures ($(\alpha_{\Delta T})_{\text{Nuclear Winter}} \sim 3$). Since the comparable value for normal conditions is $(\alpha_{\Delta T})_{\text{normal}} \sim 5$, we have preliminary quantitative evidence that Nuclear Winter will be characterised by more frequent occurences of extreme temperature fluctuations. Large scale controlled fires will be indispensible in testing these conclusions.

The biological consequences of a Nuclear Winter are likely to depend primarly on the occurences of extreme conditions, and not so much on the average drop. We therefore conclude that Nuclear winter is likely to be more severe than previously thought.

8. Acknowledgements:

We thank R. Visvanathan, P. Ladoy for help of much of the data analysis performed. We thank G. Austin, A. Doury, C. Covey, P.J. Crutzen, A. Forester, M.A. Harwell, A. Jacquard, R.W. Nicolls, S.H. Schneider, B. Stocks, S.L. Thompson, R. Turco for illuminating discussions.

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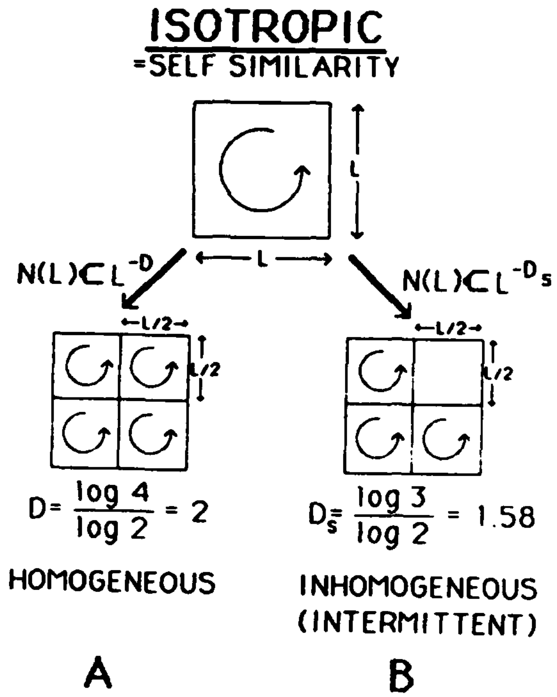

Figure 1: A schematic representation of how turbulence cascades treat the break-up of a single eddy (represented by the central square) via non-linear interactions during a single step in the cascade process. Both schemes shown here are isotropic, the left hand side is homogenous, and the right hand side intermittent.

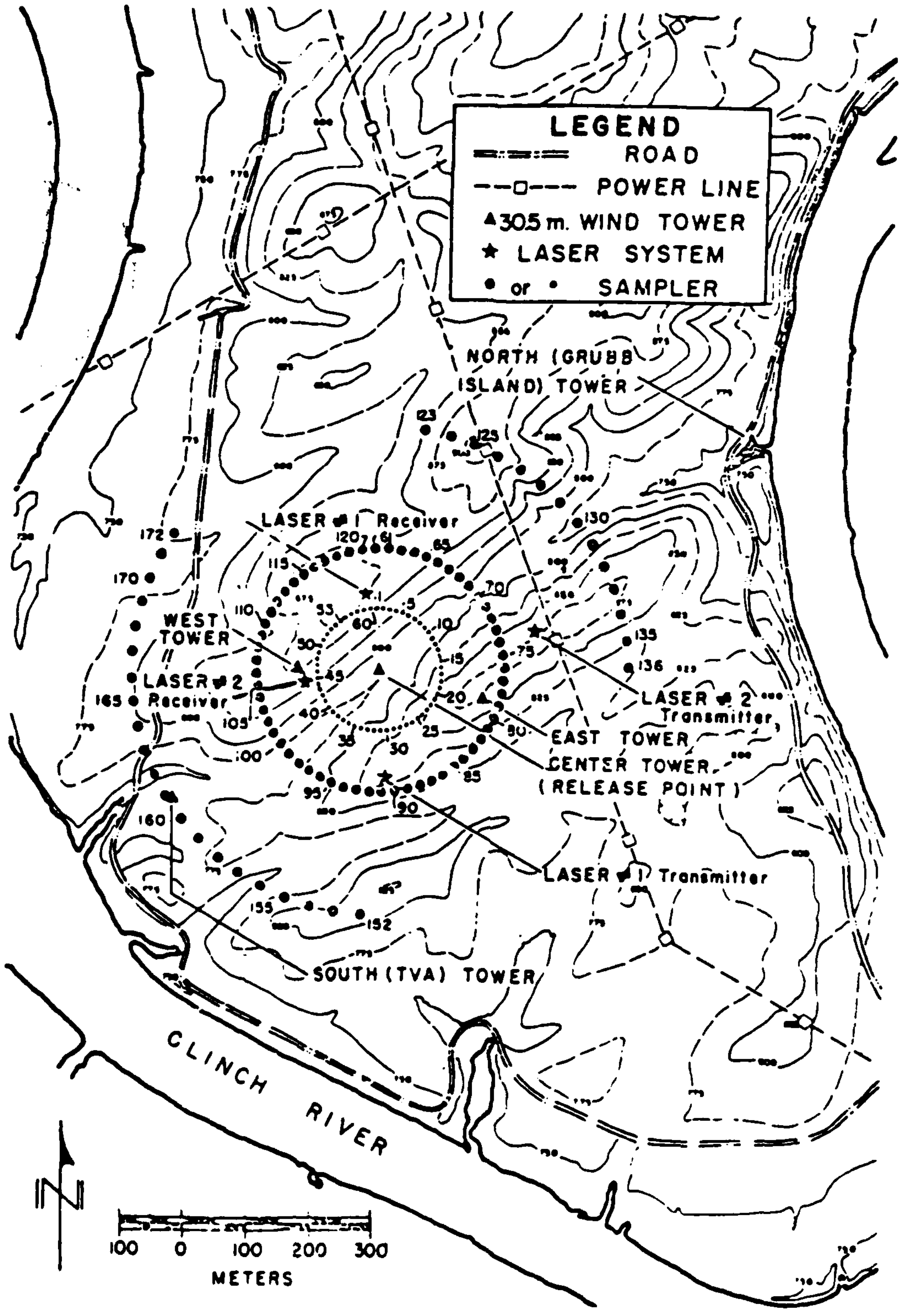

Figure 2. Detail of inner sampling area showing location of meteorological towers and laser transmitters and receivers. (Contour heights are in feet above sea level).

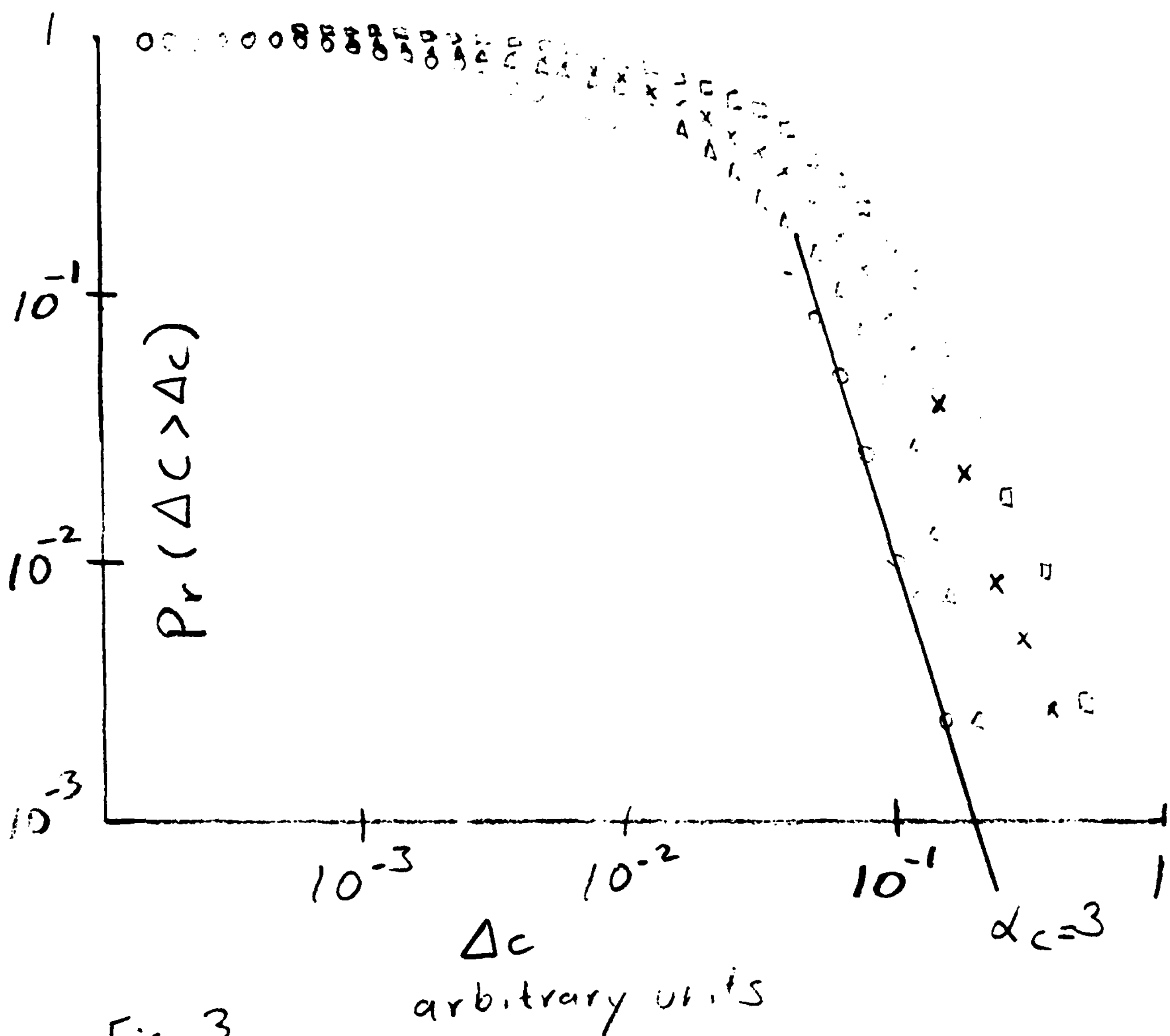

Fig. 3

o = 18 m seperation
Δ = 36 m ″
× = 72 m ″
□ = 144 m ″

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